AMERICAN HIGHWAY ENGINEERS' HANDBOOK

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The Publishers and the Editor-in-Chief will be grateful to readers of this volume who will kindly call attention to any errors of omission or of commission therein. It is intended to make our publications standard works of study and reference, and, to that end, the greatest accuracy is sought. It rarely happens that the early editions of books are free from errors; but it is the endeavor of the Publishers to have them removed, and it is therefore desired that the Editor-in-Chief may be aided in his task of revision, from time to time, by the kindly criticism of readers.

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PREFACE

The Editor-in-Chief, during the preparation of this Handbook, has had in view:

FIRST. The publication of a reference book which would include reliable and comprehensive information on all branches of highway engineering and related subjects which would prove useful to highway officials, engineers, chemists, contractors, and engineer-salesmen of highway materials and machinery.

SECOND. To include the fundamentals of administration and organization of highway departments, financing of highway improvements, preliminary investigations of highway projects, traffic investigations and regulations, grading, drainage, foundations, street cleaning, snow removal and disposal of waste; the design of highways and highway systems; the details of field and office practice; the essential elements of the chemistry and the testing of bituminous materials; and a glossary of terms used in highway engineering.

THIRD. To include in each of the sections devoted to the several types of roads and pavements, descriptions of the characteristics of materials and standard methods of testing, discussions and recommendations relative to construction methods and the use of mechanical appliances, authoritative specifications covering materials and methods of construction, reasons for failures, methods of maintenance and cost data.

FOURTH. To include essential and usable information pertaining to related fields of science which the highway engineer is called upon to use in connection with his work, such as mathematics, mechanics, structural materials, engineering geology, and the design and preservation of super- and sub-structures.

FIFTH. To present opinions of specialists pertaining to theoretical and practical details, the satisfactory solution of which has not been accomplished.

SIXTH. To include all standard tests and specifications pertaining to highway work which have been adopted by technical societies, and typical specifications and methods of practice which have been successfully used by Federal, state, county and municipal departments, commercial organizations and engineers of experience.

SEVENTH. To present, thru the medium of bibliographies, references to authoritative books and the most important literature contained in the proceedings of societies and technical periodicals.

EIGHTH. To present the subject of cost data from a conservative standpoint, giving the range of cost of materials and methods of construction under normal and average conditions, and to draw attention to the several variables which must be taken into consideration in making estimates of cost and analyzing cost records.

NINTH. The compilation of a comprehensive Index so arranged that the reader may readily find important subject headings of highway engineering, and have accessible, in one group, all references to any special subject.

The Handbook has required three years for its preparation by the Editor-in-Chief and seventeen Associate Editors and their collaborators. Its text of 1579 pages includes 559 articles, 369 tables and 607 figures. The Index occupies 78 pages and contains about 8000 references.

In the design of the Handbook, the Editor-in-Chief adopted the unit system of compilation. The field of highway engineering and closely allied subjects was divided into twenty-nine sections. In consultation with each Associate Editor, a detailed outline of each section was compiled, thus avoiding duplications of material as far as practicable. All the material submitted by the Associate Editors has been edited to obtain uniformity of arrangement, abbreviations and typography, and to connect the sections by cross references.

Some repetitions have been found advisable in cases where the same subject is treated from different viewpoints. For example, grades are discussed in the sections on Preliminary Investigations, Office and Field Practice, Planning of Roads and Road Systems, Planning of Streets and Street Systems, Comparison of Roads and Pavements, and the sections pertaining to the various types of roads and pavements. The reader, therefore, in seeking information on any given subject should consult the TABLE OF CONTENTS in order to obtain a general idea of the interrelationship of the contents of the several sections, and refer to the INDEX for a complete list of references on that subject.

At the end of each section will be found a BIBLIOGRAPHY, in which each author has been assigned a number. In case there is reference to more than one article by an author in a given section, the several articles are further designated by letters. References to the bibliographies are made in the text by enclosing in parentheses the reference number or the number followed by a letter, as, for example, (14) or (43d).

The ABBREVIATIONS used in the Handbook may be grouped in two general classes: First, periodicals and technical societies; and second, units of measurement and technical terms. The reader will find abbreviations listed after the Table of Contents under the heading, List of Abbreviations. As far as practicable standard abbreviations have been used, but unfortunately such standards do not exist for many abbreviations employed. The standard abbreviations for units of measurement as adopted by the Joint Committee of the National Engineering Societies have been used. In the case of the abbreviations most frequently used, periods have not been employed thus saving considerable space in the text. The standard abbreviations of the Century Dictionary for states, days of the week, and months of the year have been employed but, as they are in common use, they have not been included in the list of abbreviations.

Many TABLES have been included in the various sections and are referred to in the Index under the subject to which they belong. For ready reference, all mathematical tables are especially listed in the Index under the title, Tables, mathematical.

The Editor-in-Chief gratefully acknowledges his indebtedness to the technical societies, highway departments, commercial associations, periodicals, engineers, and chemists, whose writings have been quoted, and to authors who have, in a broad-minded, friendly spirit of cooperation, given permission to use certain material from copyrighted books. In all cases full credit has been given either in the text or by reference to the bibliographies. To the Associate Editors and their collaborators and to the publishers, printers and the personal staff of the Editor-in-Chief, sincere thanks are tendered for their hearty cooperation during the preparation and publication of the Handbook.

ARTHUR H. BLANCHARD.

NEW YORK, November, 1918.

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Construction

Gutters

Highway Signs

Highway Bridges

Culverts

Retaining Walls

Foundations

Guard Rails

Corrosion and Preservation of Iron and Steel

LIST OF ABBREVIATIONS

Periodicals and Technical Societies*

ABBREVIATION	TITLE
Agr. Research	Agricultural Research, Bul. U. S. Dept. Agr.
Am. Chem. Soc.	American Chemical Society
Am. City	American City
Am. City, C. Ed.	American City, City Edition
Am. City, T. & C. Ed.	American City, Town and County Edition
Am. Concrete Inst.	American Concrete Institute
Am. Electric Ry. Eng. Assn.	American Electric Railway Engineering Association
Am. Gas Inst.	American Gas Institute
Am. Gas Light Jour.	American Gas Light Journal
Am. Highway Assn.	American Highway Association
Am. Inst. Chem. Engrs.	American Institute of Chemical Engineers
Am. Munics.	American Municipalities
Am. Public Health Assn.	American Public Health Association
Am. Road Bldrs. Assn.	American Road Builders' Association
Am. Road Cong.	American Road Congress
Am. Ry. Eng. Assn.	American Railway Engineering Association
Am. Soc. C. E.	American Society of Civil Engineers
Am. Soc. Mun. Imp.	American Society for Municipal Improvements
Am. Soc. Test. Mat.	American Society for Testing Materials
Am. St. Ry. Assn.	American Street Railway Association
Am. Water Works Assn.	American Water Works Association
Am. Wood P. Assn.	American Wood Preservers' Association
Annual Conf. Mayors, N. Y.	Annual Conference of the Mayors of the State of New York
Assn. Eng. Socs.	Association of Engineering Societies
Boston Soc. C. E.	Boston Society of Civil Engineers
Brick & Clay Rec.	Brick and Clay Record
Cal. Der.	California Derrick
Can. Engr.	Canadian Engineer
Can. Geol. Survey	Canadian Geological Survey
Can. Soc. C. E.	Canadian Society of Civil Engineers
Cem. & Eng. News	Cement and Engineering News
Com. Motor	Commercial Motor

*NOTE: A periodical is not included in this list if the title used in the bibliographies is self explanatory. Examples: Better Roads, Good Roads and Southern Good Roads.

Abbreviation	Title
Con.-Cem. Age	Concrete-Cement Age
Cong. Geol. Int.	Congress Geological Internationale
Cont. Rec.	Contract Record and Engineering Review
Contr.	Contractor
Cornell C. Engr.	Cornell Civil Engineer
Electric Ry. Jour.	Electric Railway Journal
Eng. & Cont.	Engineering and Contracting
Eng. Mag.	Engineering Magazine
Eng. News	Engineering News
Eng. News-Rec.	Engineering News-Record
Eng. Rec.	Engineering Record
Eng. Standards Com. Great Britain	Engineering Standards Committee of Great Britain
Engrs. Club Phila.	Engineers Club of Philadelphia
Engrs. Soc. Penn.	Engineers Society of Pennsylvania
Engrs. Soc. Western Penn.	Engineers Society of Western Pennsylvania
Franklin Inst.	Franklin Institute
Highway Contr.	Highway Contractor and Road Builder
Ill. Eng. Exp. Sta.	Illinois Engineering Experiment Station
Ill. Highways	Illinois Highways
Ill. Soc. Engrs.	Illinois Society of Engineers
Ind. Eng. Soc.	Indiana Engineering Society
Inst. C. E.	Institution of Civil Engineers of Great Britain
Inst. Ind. Research	Institute of Industrial Research, Washington, D. C.
Int. Cong. App. Chem.	International Congress of Applied Chemistry
Int. Road Cong.	International Road Congress
Jour. Ind. & Eng. Chem.	Journal of Industrial and Engineering Chemistry
Mun. Eng.	Municipal and County Engineering
Mun. Engrs.	Municipal Engineers of New York
Mun. Jour.	Municipal Journal
Nat. Conf. City Plan.	National Conference on City Planning
Nat. Conf. Concrete Road Building	National Conference on Concrete Road Building
Nat. Highways Assn.	National Highways Association
Nat. Mun. Rev.	National Municipal Review
Nat. Paving Brick Mnfrs. Assn.	National Paving Brick Manufacturers Association
N. Y. State Mus.	New York State Museum
Ore. Soc. Engrs.	Oregon Society of Engineers
Pacific Bldr. & Engr.	Pacific Builder and Engineer
Pacific Munics.	Pacific Municipalities
Paint Mnfrs. Assn. U. S.	Paint Manufacturers Association of the United States

Abbreviation	Title
Pan-Am. Road Cong.	Pan-American Road Congress
Penn. Highway News	Pennsylvania Highway News
Pet. Gas.	Petroleum Gazette
Pet. W.	Petroleum World
Pub. Service Rec. N. Y.	Public Service Record of New York
Rock Prods.	Rock Products
Ry. Age Gaz.	Railway Age Gazette
Ry. Rev.	Railway Review
Sci. Am.	Scientific American
Soc. Chem. Ind.	Society of Chemical Industry
Spec. Com. Mat. Road Cons.	Special Committee, Materials for Road Construction, Am. Soc. C. E.
Street Ry. Jour.	Street Railway Journal
Surveyor	Surveyor and Municipal and County Engineer
Town Plan. Rev.	Town Planning Review
U. S. Bur. Mines	United States Bureau of Mines
U. S. Bur. Standards	United States Bureau of Standards
U. S. Dept. Agr.	United States Department of Agriculture
U. S. Forest Service	United States Forest Service
U. S. Geol. Survey	United States Geological Survey
U. S. O. P. R.	United States Office of Public Roads and Rural Engineering
Western Soc. Engrs.	Western Society of Engineers

Units of Measurement and Technical Terms

Abbreviation	Title	Abbreviation	Title
A. C.	asphalt cement	hr	hours
B	Baumé	in	inches
bbl	barrel	kg	kilograms
B. S.	back sight	km	kilometers
B. T. U.	British thermal units	lb	pounds
C	Centigrade	lin	linear
cc	cubic centimeters	log	logarithm
CCl_4	carbon tetrachloride	m	meters
cm	centimeters	mg	milligrams
c.p.	chemically pure	min	minutes
CS_2	carbon disulphide	mm	millimeters
cu	cubic	oz	ounces
F	Fahrenheit	P. C.	point of curve
f.o.b.	free on board	P. I.	point of intersection
F. S.	fore sight	P. T.	point of tangency
ft	feet	R. A.	refined asphalt
g	grams	rev per min	revolutions per minute
gal	gallons	sec	seconds
G. W. L.	ground water level	sp. gr.	specific gravity
H. I.	height of instrument	sq	square
h.p.	horse-power	yd	yards

SECTION 1

TERMINOLOGY OF HIGHWAY ENGINEERING

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1. General Considerations

Since 1910 considerable attention has been devoted to the formulation of a terminology of highway engineering in order that literature and specifications might be easily understood, and costly mistakes avoided on the part of engineers, contractors, and others connected with highway work due to misinterpretation of terms in contracts covering the construction and maintenance of highways.

The terminology of highway engineering has been developed and standardized mainly thru the work of committees of the Permanent International Association of Road Congresses, the American Society of Civil Engineers and the American Society for Testing Materials. Some terms used in highway engineering have been defined and explained in reports of the Engineering Standards Committee of Great Britain and of committees of the American Society for Municipal Improvements, the American Railway Engineering Association, the American Wood Preservers' Association, the National Conference on Concrete Road Building, the American Concrete Institute, the City Planning Conference, and the Society for the Promotion of Engineering Education.

Key to American Terminology. The following key indicates the society, committee or individual proposing or adopting certain definitions given in Art. 2. In cases where no indicators or references are given, the definitions are proposed by the author.

*Adopted by Am. Soc. Test. Mat. (12a).

‡Proposed by Com. D-4, on Road Materials, Am. Soc. Test. Mat (12b), but not adopted (1917) by the Society.

†Proposed by Spec. Com. Mat. Road Cons., Am. Soc. C. E. (10).

**Adopted by Am. Ry. Eng. Assn. (9).

††Proposed by Com. on Nomenclature, Am. Concrete Inst. (7).

‡‡Proposed by Prevost Hubbard (5).

***Proposed by James F. Kemp (6).

British Terminology. For the use of British highway officials, engineers and chemists, and Americans who read highway engineering literature

emanating from Great Britain, the definitions of certain terms peculiar to British practice, and definitions of terms used in American practice but which are given a different meaning in Great Britain, have been included in Art. 2. In each instance the term has been followed by the word British. The British definitions have been taken from the report of British Engineers (16) to the Third International Road Congress, London, 1913, designated by a *; the report of the Engineering Standards Committee (15), designated by a †; and from the writings of Boulnois (3a) and (13), designated by a ‡. In Art. 3 will be found explanations relative to the British terminology covering bituminous material terms presented by the Engineering Standards Committee of Great Britain and discussion of this nomenclature by Committee D-4 on Road Materials, Am. Soc. Test. Mat.

2. Definitions of Terms Used in Highway Engineering

Abrasion. The act of wearing or rubbing off or away by friction or attrition. (Century Dictionary.)

Abutment.** A supporting wall carrying the end of a bridge or span and sustaining the pressure of the abutting earth. The abutment of an arch is commonly called a bench wall.

Aggregate.‡† The inert material, such as sand, gravel, shell, slag or broken stone, or combinations thereof, with which the cementing material is mixed to form a mortar or concrete.

Aggregate (British*). The material comprising the main portion of the surfacing.

Amorphous. A textular term used to describe a rock structure without definite form or crystalline composition.

Aqueous Rocks. Rocks which have been formed thru the agency of water.

Arkose. A coarse feldspathic sandstone.

Artificial Foundation. See Foundation.

Ashlar.** A squared or cut block of stone of rectangular dimensions.

Asphalt.†* Solid or semi-solid native bitumens, solid or semi-solid bitumens obtained by refining petroleums, or solid or semi-solid bitumens which are combinations of the bitumens mentioned with petroleums or derivatives thereof, which melt on the application of heat, and which consist of a mixture of hydrocarbons and their derivatives of complex structure, largely cyclic and bridge compounds.

Asphalt (British †) is a road material consisting of a mixture of bitumen and finely graded mineral matter. The mineral matter may range from an impalpable powder up to material of such a size as will pass thru a sieve having square holes of ¼ in size.

Asphalt Block Pavement.† One having a wearing course of previously prepared blocks of asphaltic concrete.

Asphalt Cement.† A fluxed or unfluxed asphaltic material, especially prepared as to quality and consistency, suitable for direct use in the manufacture of asphaltic pavements, and having a penetration of between 5 and 250. Note: Commonly designated in paving work as A. C.

Asphalte (British †). Limestone naturally impregnated with bitumen.

Asphaltenes.†* The components of the bitumen in petroleums, petroleum products, malthas, asphalt cements, and solid native bitumens, which are soluble in carbon disulphide, but insoluble in paraffin naphthas.

Asphaltic.† Similar to, or essentially composed of, asphalt.

Asphaltic Concrete Pavement. One composed of broken stone, broken slag, gravel or shell, with or without sand, Portland cement, fine inert

material, or combinations thereof, and an asphalt cement incorporated together by a mixing method.

Asphaltic Macadam Pavement. One having a wearing course of macadam with the interstices filled by a penetration method with an asphaltic binder.

Asphaltic Petroleum.‡‡ Petroleum which, upon evaporation or fractional distillation without blowing, will yield an asphalt cement.

Attrition (British *). Wear due to the mutual friction of two surfaces of the same material moving over each other.

Backing.** That portion of a masonry wall or structure built in the rear of the face. It must be attached to the face and bonded with it. It is usually of a cheaper grade of work than the face.

Bank Gravel.‡ Gravel found in natural deposits, usually more or less intermixed with fine material, such as sand or clay, or combinations thereof; gravelly clay, gravelly sand, clayey gravel and sandy gravel, indicate the varying proportions of the materials in the mixture.

Barrel (British ‡). The camber, contour, cross-section or crossfall of a surface of a carriageway or footway.

Basalt. A general name given to dark, basic, volcanic rocks of wide distribution, and in a restricted sense employed as a rock name for porphyritic and felsitic rocks consisting of augite, olivine, and plagioclase with varying amounts of a glassy base which may entirely disappear.

Base.† Artificial foundation.

Batter.** The slope or inclination of the face or back of a wall from a vertical plane.

Batter Pile.** One driven at an inclination to resist forces which are not vertical.

Bed (British *). Support of foundations.

Berme.** (1) The space left between the top or toe of slope and excavation made for intercepting ditches or borrow pits. (2) An approximately horizontal space introduced in a slope.

Binder.† (1) A foreign or fine material introduced into the mineral portion of the wearing surface for the purpose of assisting the road metal to retain its integrity under stress, as well as, perhaps, to aid in its first construction. (2) The course, in a sheet-asphalt pavement, frequently used between the concrete foundation and the sheet-asphalt mixture of graded sand and asphalt cement.

Binder Course.‡‡ A rather coarse bituminous aggregate containing a relatively small percentage of bitumen, commonly used as an intermediate course between the foundation and wearing course of a sheet-asphalt pavement.

Bitumen.†* A mixture of native or pyrogenous hydrocarbons and their non-metallic derivatives, which may be gases, liquids, viscous liquids, or solids, and which are soluble in carbon disulphide.

Bitumen (British †) is a generic term for a group of hydrocarbon products soluble in carbon disulphide, which either occur in nature or are obtained by the evaporation of asphaltic oils. The term shall not include residues from paraffin oils or coal tar products. Note: Commercial materials may be described as Bitumen if they contain not less than 98% of pure Bitumen as defined above.

Bituminous Aggregate.‡‡ A mineral or other aggregate containing bitumen as a cementing medium.

Bituminous Cement.† A bituminous material suitable for use as a binder having cementing qualities which are dependent mainly on its bituminous character.

Bituminous Concrete Pavement.† One composed of broken stone, broken slag, gravel, or shell, with or without sand, Portland cement, fine inert material, or combinations thereof, and a bituminous cement incorporated together by a mixing method.

Bituminous Emulsion.‡ A liquid mixture in which minute globules of bitumen are held in suspension in water or a watery solution.

Bituminous Filler.‡‡ Bituminous material primarily used for filling the joints in brick, block, concrete, or other pavements.

Bituminous Macadam Pavement.† One having a wearing course of macadam with the interstices filled by a penetration method with a bituminous binder.

Bituminous Mastic.‡‡ A bituminous aggregate, the mineral portion of which consists of very fine particles.

Bituminous Material.† Material containing bitumen as an essential constituent.

LIQUID BITUMINOUS MATERIALS.* Those having a penetration at 25° C (77° F), under a load of 50 g applied for 1 sec, of more than 350.

SEMI-SOLID BITUMINOUS MATERIALS.* Those having a penetration at 25° C (77° F), under a load of 100 g applied for 5 sec, of more than 10, and a penetration at 25° C (77° F), under a load of 50 g applied for 1 sec, of not more than 350.

SOLID BITUMINOUS MATERIALS.* Those having a penetration at 25° C (77° F), under a load of 100 g applied for 5 sec, of not more than 10.

Bituminous Pavement.† One composed of broken stone, broken slag, gravel, shell, sand, or fine inert material, or combinations thereof, and bituminous cement incorporated together.

Bituminous Rock.‡‡ Rock naturally impregnated with petroleum or asphalt.

Bituminous Surface.† A superficial coat of bituminous material with or without the addition of stone or slag chips, gravel, sand, or material of similar character.

Blanket.† See Carpet.

Bleeding.† The exudation of bituminous material on the roadway surface after construction.

Blinding Material (British*). Material used for spreading over surface tarring or as a surface dressing for water-bound macadam.

Blown Petroleums.* Semi-solid or solid products produced primarily by the action of air upon liquid native bitumens which are heated during the blowing process.

Bog.** Soft, spongy ground, usually wet and composed of more or less vegetable matter.

Bond.† The combined action of inertia, friction, and of the forces of adhesion and cohesion which helps the separate particles composing a crust or pavement to resist separation under stress. Mechanical bond is the bond produced almost wholly, in a well built broken stone macadam road, by the interlocking of angular fragments of stone and the subsequent filling of the remaining interstices with the finer particles.

Bond.** In stone or brick masonry, the mechanical disposition of stone, brick or other building blocks by overlapping to break joints.

Borrow Pit.** An excavation made for the purpose of obtaining material.

Bottoming (British *). See Foundation.

Boulder Pavement (British *). Road paving formed of cobblestones.

Bound.† Bonded.

Bituminous-Bound.† Bonded with the aid of bituminous material.

Water-Bound.† Bonded with the aid of water.

Breasts (British *). See Quarters.

Breccia. A rock composed of angular fragments larger than sand grains, cemented together, and often presenting a variety of colors.

Breeze (British ‡). Small coal, ashes, clinker, or cinders; sometimes used for binding.

Brick Pavement.† One having a wearing course of paving bricks or blocks.

Bridge.† A structure for the purpose of carrying traffic over a gap in the road-bed measuring 10 ft or more in the clear span.

Brush.** Trees less than 4-in stump-top diameter, shrubs or branches of trees that have been cut off.

Burnt Clay.** A clay or gumbo which has been burned into material for ballast.

By-Pass Road (British ‡). Generally applied to a road which diverts the traffic for a short distance so as to avoid congestion of traffic in a town or elsewhere.

Camber of a Bridge.† The rise of its center above a straight line thru its ends.

Camber of a Road.† See Crown.

Cap.** A block used to protect the head of a pile and to hold it in the leads during driving.

Carbenes.†* The components of the bitumen in petroleums, petroleum products, malthas, asphalt cements, and solid native bitumens, which are soluble in carbon disulphide, but insoluble in carbon tetrachloride.

Carpet.† A bituminous surface of appreciable thickness, generally formed on top of a roadway by the application of one or more coats of bituminous material with gravel, sand, or stone chips added.

Carpeting Medium.‡‡ Bituminous material applied to a road surface primarily for protecting the road proper from the wear and tear of traffic thru the formation of a mat or carpet covering.

Carriageway (British *). Portion of road used by vehicles.

Catchment Area (British ‡). The area from which the surface or storm water is gathered.

Catchpit (British ‡). A pit at the side of the road into which the surface water drains. Usually called a gully or gully pit.

Causeway (British ‡). A narrow road or street paved with stone. Generally applied to a raised road or a short road to a ford or ferry.

Cellular. A textural term used to describe a rock structure containing cells due to weathering out of some constituent.

Cement.** A material of one of the three classes, Portland, Natural, and Puzzolan, possessing the property of hardening into a solid mass when mixed with water.

Cement.† An adhesive substance used for uniting particles of other materials to each other. Ordinarily applied only to calcined cement rock, or to artificially prepared, calcined, and ground mixtures of limestone and silicious materials. Sometimes used to designate bituminous binder used in bituminous pavements, when the expression bituminous cement is understood to be meant.

Cement-Concrete.† An intimate mixture of gravel, shell, slag, or broken stone particles with certain proportions of sand or similar material, cement, and water, made previous to placing.

Cement-Concrete Pavement.† One having a wearing course of hydraulic cement-concrete.

Cemented.† Bonded. Referring to water-bound macadam, the term cemented is used to designate that condition existing when, after rolling the stone forming the crust, the remaining voids have been filled with the finer sizes, and the stone dust or flour has, under the action of water, taken a set, as does cement itself.

Cement Gun.†† A trade name applied to an apparatus used for the placing of mortar under pressure, the characteristics being that the mortar is forced dry to the nozzle, hydration taking place at the nozzle and coincident with the application.

Cement Wash.†† An application of a mixture of cement and water generally applied with a brush to the surfaces of concrete work, to reduce the permeability or to give a uniform color and appearance to the concrete work.

Channels (British*). The outer edges of the carriageway.

Chats.** Tailings from mills in which zinc, lead, silver, and other ores are separated from the rocks in which they occur.

Cheek Crusher (British ‡). A stone breaker, with jaws or cheeks, as distinguished from a roller or drum crusher.

Chert.* Compact silicious rock formed of chalcedonic or opaline silica, or both.

Chip Pavement (British ‡). A pavement composed of irregular stone spalls in the form of a mosaic.

Chips.† Small angular fragments of stone or slag containing no dust.

Cinders.** The residue from the coal used in locomotives and other furnaces.

Clay.† Finely divided earth, generally silicious and aluminous, which will pass a 200-mesh sieve.

Clay (British*). Fine grained non-indurated sedimentary deposit, plastic when wet.

Clearing.** Removing natural and artificial perishable obstructions to grading.

Clinker.‡ Generally a fused or partly fused by-product of the combustion of coal, but also including lava and Portland-cement clinker, and partly vitrified slag and brick.

Coal Tar.†* The mixture of hydrocarbon distillates, mostly unsaturated ring compounds, produced in the destructive distillation of coal.

Coat.† See Carpet. (1) The total result of one or more single surface applications. (2) To apply a coat.

Coke-Oven Tar.†* Coal-tar produced in by-product coke ovens in the manufacture of coke from bituminous coal.

Colloidal. A textural term used to describe a jelly or glue-like rock structure.

Composite Paving (British*). Road surface made of artificial stone.

Compressed Asphalte (British ‡). Natural rock-asphalte ground into powder, heated and rammed to form a road surface.

Concrete.†† An artificial stone formed by the mixture of hydraulic cement with water and an aggregate composed of hard inert particles of various sizes.

Consistency.†* The degree of solidity or fluidity of bituminous materials.

Contour.** The line of intersection between a horizontal plane and a given surface.

Coping.** A top course of stone or concrete, generally slightly projecting, to shelter the masonry from the weather, or to distribute the pressure from exterior loading.

Corduroy (British ‡). A term given to the surface of a carriageway that has become ribbed or corrugated.

Corduroy Road. A roadway constructed by means of small logs laid transversely.

Core (British ‡). The heart or inner part of anything. A term sometimes applied to the subcrust of a carriageway.

Corrugated Bar.†† A steel bar for reinforcing concrete and which has square or oblong projections on its surface formed by special rolls.

Corrugated Surface (British *). Undulating wavy-surface.

Course.† One or more layers of road metal spread and compacted separately for the formation of the road or pavement. Courses are usually referred to in the order of their laying as first course, second course, third course, etc. Also a single row of blocks in a pavement.

Creep. A slow, natural, downward movement of loose material on hillsides (see Sect. 3, Art. 12).

Creeping (British *). Gradual shearing of the road crust.

Creosoting Oil.‡‡ Tar distillates, tars, and mixtures of tars with tar distillates which are used by a process of impregnation in the preservation of wood. Note: This term was originally confined to the heavier coal-tar distillates carrying a large proportion of the creosols which were present in the tar before distillation.

Cross-Grip (British ‡). A cutting or channel across a road to divert the surface water from one side to the other.

Crown.† The rise in cross-section from the lowest to the highest part of the finished roadway. It may be expressed either as so many inches, or tenths of a foot, or as a rate per foot of distance from side to center, for example, the crown is 4 in, or the crown is ½ in to the foot.

Crown (British *). Highest point of cross-section or carriageway, usually the center.

Crusher-Run.†* The total unscreened product of a stone crusher.

Crusher-Run Stone.† The product of a stone crusher, unscreened except for the removal of the particles smaller than remaining on about a ¼-in screen.

Crusher Sand (British ‡). The sand or small stuff remaining after stone has been crushed or broken in a stone breaker.

Crust.† That portion of a macadam or similar roadway above the foundation consisting of the road metal proper with its bonding agent or binder.

Crust (British ‡). The external covering of a carriageway; it is sometimes qualified as upper and lower crust if there are two layers making up the formation.

Crystalline. A textural term used to describe a rock structure similar to that of granite.

Cul-de-Sac. A street or alley which has no outlet at one end. (Century Dictionary).

Culvert.† A structure for the purpose of carrying traffic over a gap in the road-bed, measuring less than 10 ft in clear span.

Culvert.** An arched, circular or flat covered opening of timber, iron, brick, or masonry, carried under the road-bed for the passage of water, or for other purposes.

Cups (British ‡). A term applied to hollows or depressions in the surfaces of a carriageway.

Cut-Back Products.* Petroleum, or tar residuums, which have been fluxed with distillates.

Dandy (British ‡). A portable can for the distribution of tar or bituminous binder. Also used to designate a portable mixing vessel.

Dead Oils.†* Oils, with a density greater than water, which are distilled from tars.

Deformed Bar.†† A steel bar for reinforcing concrete and which has projections on its surface in order to secure a mechanical bond between the concrete and the steel. These projections are formed either by passing the bar thru specially shaped rolls or by twisting the bar.

Dehydrated Tars.†* Tars from which all water has been removed.

Diabase. Crystalline-granular igneous rocks, consisting essentially of plagioclase, augite, and magnetite, with or without olivine.

Diorite. Granitoid rock consisting essentially of plagioclase and hornblende, with usually more or less biotite.

Disintegrate (British *). Loosening or breaking up.

Disintegrated Granite.** A natural deposit of granite formation, which on removal from its bed by blasting or otherwise, breaks into particles of size suitable for ballast.

Ditch.† The open side drain of a roadway, usually deep in proportion to its width, and unpaved.

Dolerite.*** Coarsely crystalline basalts.

Dolomite. A native carbonate of calcium and magnesium, occurring as a crystallized mineral, and also on a large scale in granular crystalline rock masses.

Dowels.** Metal bars used to connect two sections of masonry.

Drainage.† Provision for the disposition of water. See Sub-drainage, Surface Drainage and V-Drainage.

Drainage.** The interception and removal of water from, upon or under the roadway.

Dressing.** The finish given to the surface of stones or concrete.

Dribbling (British *). Placing small quantities of material in road depressions to restore the surface to its original shape.

Drop Hammer.** One which is raised by means of a rope and then allowed to drop.

Dry Masonry.** Masonry in which stones are built up without the use of mortar.

Dust.† Earth or other matter in fine, dry particles, so attenuated that they can be raised and carried by air currents. The product of the crusher passing thru a fine sieve.

Dust Layer.† Material applied to a roadway for temporarily preventing the formation or dispersion under traffic of distributable dust.

Earth Road.† A roadway composed of natural earthy material.

Elevation or Height.** The distance of any given point above or below an established plane or datum.

Embankment or Fill.** A bank of earth, rock or other material constructed above the natural ground surface.

Emulsion.† A combination of water and oily material made miscible with water thru the action of a saponifying or other agent. See Bituminous Emulsion.

Encased Knot.* An encased knot is one whose growth rings are not inter-

grown and homogeneous with the growth rings of the piece it is in. The encasement may be partial or complete; if intergrown partially or so fixed by growth or position that it will retain its place in the piece, it shall be considered a sound knot; if completely intergrown on one face, it is a water-tight knot.

English Bond.** That disposition of bricks in a structure in which each course is composed entirely of headers or of stretchers.

Epidiorite. Diabase whose augite is in part altered to green hornblende.

Excavation or Cutting.** (1) The cutting down of the natural ground surface; (2) The material taken from cuttings, borrow pits or foundation pits; (3) The space formed by removing material.

Expanded Metal.†† A form of concrete reinforcement made of sheet steel which has been slit and pulled out to form a diamond mesh.

Expansion Joint.† A separation of the mass of a structure, usually in the form of a joint filled with elastic material, which will provide opportunity for slight movement in the structure.

Extrados.** The outer or convex surface of an arch.

Fat.† Containing an excess. A fat asphaltic mixture is one in which the asphalt cement is in excess and the excess is clearly apparent.

Felsite. Finely crystalline varieties of quartz-porphyries, porphyries, or porphyrites that have few or no phenocrysts, and that, therefore, give but slight indications to the unaided eye of their actual mineralogical composition.

Filler.† (1) Relatively fine material used to fill the voids in the aggregate. (2) Material used to fill the joints in a brick or block pavement.

Fine Pointed.** Having irregular surface, the variations of which do not exceed ¼ in from the pitch line.

Fixed Carbon.†* The organic matter of the residual coke obtained upon burning hydrocarbon products in a covered vessel in the absence of free oxygen.

Flemish Bond.** That disposition of bricks in a structure in which the headers and stretchers alternate in each course, the header being so placed that the outer end lies on the middle of a stretcher in the course below.

Floating (British*). A thin layer of cement and sand or similar material laid to form a true bed for wood blocks, etc.

Flour.† Finely ground rocks or minerals pulverized to an impalpable product.

Flush Coat.† See Seal Coat.

Flushing.† (1) Completely filling the voids. (2) Washing a pavement with an excess of water.

Flux.†* Bitumens, generally liquid, used in combination with harder bitumens for the purpose of softening the latter.

Foliated. A textural term used to describe a rock structure which has a tendency to split along lines of stratification.

Footway.† The portion of the highway devoted especially to pedestrians. A sidewalk.

Foundation.† The portion of the roadway below and supporting the crust or pavement.

Artificial Foundation.† That layer of the foundation especially placed on the subgrade for the purpose of reinforcing the supporting power of the latter itself, and composed of material different from that of the subgrade proper.

Natural Foundation.† The natural earthy material below and support-

ing the artificial foundation or, if there is no artificial foundation, the crust or pavement.

Free Carbon.†* In tars, organic matter which is insoluble in carbon disulphide.

Free Haul.** The distance within which material is moved without extra compensation.

Gabbro. Igneous rocks of granitoid texture, consisting of plagioclase and diallage, but as now employed, any monoclinic pyroxene may be present, with or without diallage.

Gas-House Coal Tar.†* Coal tar produced in gas-house retorts in the manufacture of illuminating gas from bituminous coal.

Gauge (British ‡). A standard of measure. The term gauge has been adopted by the Engineering Standards Committee to designate the standard group of sizes into which broken stone has been divided, and the term size has been adopted for the sub-division of the gauge.

Gin Pole.†† A pole or mast to which a block and tackle are attached for the purpose of hoisting materials.

Glass. A textural term used to describe an amorphous rock structure formed by the quick chilling of a fused lava.

Gneiss.*** Laminated or foliated granitoid rock that corresponds in mineralogical composition to some one of the plutonic rocks.

Grade.† (1) The profile of the center of the roadway, or its rate of rise or fall. (2) Elevation. (3) To establish a profile by cuts and fills or earthwork. (4) To arrange by sizes, broken stone, gravel, sand, or combinations of such materials.

Graded (British *). Sorted according to size.

Gradient.** The rate of inclination of the grade-line from the horizontal.

Granite.* A granitoid igneous rock consisting of quartz, orthoclase, more or less oligoclase, biotite, and muscovite. See Disintegrated Granite.

Granitoid.* A textural term to describe those igneous rocks which are entirely composed of recognizable minerals.

Granolithic.†† A floor surface formed by a mixture of cement and very fine crushed stone and sometimes an addition of sand, it being troweled smooth while wet and allowed to harden.

Granular. A textural term used to describe a rock structure made up of distinct grains.

Gravel.† Small stones or pebbles usually found in natural deposits more or less intermixed with sand, clay, etc, but in which mixture the particles which will not pass a 10-mesh sieve predominate.

Gravel.** Worn fragments of rock, occurring in natural deposits, that will pass thru a 2½-in ring and be retained upon a 10-mesh sieve.

Greywacke. Metamorphosed, shaly sandstones that yield a tough, irregular breaking rock.

Grit.‡† Stone chips, slag chips, or small gravel.

Grit (British *). A coarse grained sandstone.

Ground Water. Water which sinks into the earth and moves thru cracks and pores in soil or rock (see Sect. 3, Art. 12).

Grout.** A mortar of liquid consistency which can easily be poured.

Grubbing.** Removing stumps and roots.

Gulley (British *). Trap or opening leading into drain.

Gumbo.** A term commonly used for a peculiarly tenacious clay, containing no sand.

Gutter.† The artificially surfaced and generally shallow waterway

provided usually at the sides of the roadway for carrying surface drainage. Occasionally used synonymously with ditch, but incorrectly so, as gutters are always paved or otherwise surfaced, and ditches are not.

Guy Derrick.†† A derrick, the mast of which is secured by guy ropes to "dead men" or to other anchorages.

Hand Pitched (British ‡). A term used to designate a foundation, or bottom course, of a carriageway constructed of large stones, placed carefully by hand.

Hard Core (British *). Materials such as chalk, brick, rubbish, clinker, etc, used for the foundation of a road.

Hardness. The property of a material which enables it to resist abrasion of its surface.

Hardpan. A soil which may be either (1) a very dense subsoil, such as tough clay; (2) a cemented layer in the soil, where ground waters have precipitated a local binder of silica carbonates, iron oxides, etc; or (3) dense clayey glacial drift (see Sect. 3, Art. 8).

Hardwood (British *). Jarrah, Karri, oak.

Haunches.† The sides or flanks of a roadway. Sometimes also called quarters.

Header.** A stone which has its greatest length at right angles to the face of the wall, and which bonds the face stones to the backing.

Heartwood.** The older and central part of a log, usually darker in color than sapwood. It appears in strong contrast to the sapwood in some species, while in others it is but slightly different in color.

Highway.† The entire right-of-way devoted to public travel, including the sidewalks and other public spaces, if such exist.

Hoggin (British ‡). A name sometimes given to a red marly gravel, used as a binder.

Holocrystalline. A textural term used to describe a rock structure that consists entirely of crystallized minerals.

Hornblende Schist. A schistose rock consisting chiefly of black or dark-green hornblende, but often interlaminated with feldspar, quartz, or mica.

Humus. Soil formed by the decomposition of vegetable matter on the surface of the ground.

Igneous Rocks. Rocks which have been formed by mineral matter flowing upward in a molten condition and cooling near the surface.

Intercepting Ditch.** An open artificial waterway for preventing surface water from flowing over the slopes of a cut or against the foot of an embankment.

Intrados.** The inner or concave surface of an arch.

Islet (British ‡). Sometimes used to designate a refuge or place of safety for pedestrians on a carriageway.

Kentish Rag (British*). Rough-textured, semi-crystalline, sandy limestone.

Kerb (British*). Dividing line between the footway and the carriageway.

Kidney (British ‡). The name given to small, rounded, water-worn boulders, formerly much used for paving.

Knots. See Encased Knot, Large Knot, Loose Knot, Pin Knot, Pith Knot, Rotten Knot, Round Knot, Sound Knot and Standard Knot.

Laitance.** A sediment from cement of concrete deposited in water, or of concrete, when water is worked to the surface.

Laminated. A textural term used to describe a banded structure which is characteristic of many sedimentary rocks.

Large Knot.* A large knot is a sound knot, more than 1½ in in diameter.

Layer.† A course made in one application.

Leads.** The upright parallel members of a pile driver which support the sheaves used to hoist the hammer and piles, and which guide the hammer in its movement.

Licking-Up (British ‡). A term applied to the adherence of the surface of a carriageway to the face of a wheel or of a roller.

Limestone.*** Rock composed essentially of calcium carbonate.

Loam.†‡ Finely divided earthy material containing a considerable proportion of organic matter.

Loose Knot.* A loose knot is one not firmly held in place by growth or position.

Macadam.† A road crust composed of stone or similar material broken into irregular angular fragments compacted together so as to be interlocked and mechanically bound to the utmost possible extent.

Macadam (British*). A general term for broken stone used for road surfacing.

Malthas.‡‡ Very viscous petroleums.

Marble. Limestones which have sufficiently close texture to take a polish.

Marl. Calcareous clay containing a minimum of 15% of carbonate of lime and a maximum of 75% of clay.

Massive. A textural term used to describe igneous rocks that show no stratification.

Mastic.† A mixture of bituminous material and fine mineral matter suitably made for use in highway construction and for application in a heated condition.

Mastic Asphalte (British ‡). A term applied to asphalte melted and laid in an adhesive condition on a carriageway or footway, as distinguished from compressed asphalte.

Mat.† See Carpet.

Matrix.*† The binding material or mixture of binding material and fine aggregate in which the large aggregate is embedded or held in place.

Mesh.†‡ The square opening of a sieve.

Metal.† See Road Metal.

Metalling (British *). (1) Broken stone and other materials composing road surface. (2) To lay coating of broken stone on road.

Metamorphic Rocks. Rocks which have been changed by dynamic or chemical agencies from their original condition.

Mortar.† A mixture of fine material such as sand, cement, and water or other liquid suitably proportioned and incorporated together for the purpose for which it is used.

Mush.† A greasy mud sometimes found on bituminous crusts.

Mushroomed (British*). Raising of a wood paved surface, owing to insufficient allowance for lateral expansion.

Naphthalene.‡‡ A solid crystalline highly volatile hydrocarbon occurring principally in tars, and having the chemical formula $C_{10}H_8$.

Native Asphalt.* Asphalt occurring as such in nature.

Native Bitumen (British†) is bitumen found in nature, carrying in suspension a variable proportion of mineral matter. The term Native Bitumen shall not be applied to the residuals from the distillation of asphaltic oils.

Native or Rock Asphalt (British†) is a rock which has been impregnated by nature with bitumen.

Natural Bed.** The surfaces of a stone parallel to its stratification.

Natural Cement.** This term shall be applied to the finely pulverized product resulting from the calcination of an argillaceous limestone at a temperature only sufficient to drive off the carbonic acid gas.

Natural Foundation. See Foundation.

Norite.*** Rock of the gabbro family that consists of plagioclase and orthorhombic pyroxene, usually hyperosthene.

Normal Temperature.‡† As applied to laboratory observations of the physical characteristics of bituminous materials, is 25° C (77° F).

Oil Asphalt.‡‡ Asphalt manufactured directly from petroleum.

Oil-Gas Tars.*† Tars produced by cracking oil vapors at high temperatures in the manufacture of oil-gas.

Overhaul.** The number of cubic yards moved thru the overhaul distance multiplied by the overhaul distance in units of 100 ft.

Overhaul Distance.** The distance beyond the free-haul limit that material is hauled in constructing the roadway, for which extra compensation is allowed.

Palliative.† A short-lived dust layer.

Paraffin Petroleum.‡‡ Petroleum which, upon evaporation or fractional distillation, will yield a greasy residue containing an appreciable quantity of paraffin hydrocarbons.

Patching.† Repairing or restoring small isolated areas in the surface of the metaled or paved portion of the highway.

Pavement.† The wearing course of the roadway or footway, when constructed with a cement or bituminous binder, or composed of blocks or slabs, together with any cushion or binder course.

Pea Gravel.† Clean gravel, the particles of which approximate peas in size.

Peat. Soil formed by the decomposition of vegetable matter under water.

Pegmatite. Very coarse granites, such as have large quartz, feldspar, muscovite, biotite, tourmaline, beryl, and other characteristic minerals.

Penetration.‡ The consistency of a bituminous material expressed as the distance that a standard needle vertically penetrates a sample of the material under known conditions of loading, time and temperature. Where the conditions of test are not specifically mentioned, the load, time and temperature are understood to be 100 g, 5 sec, and 25° C (77° F), respectively, and the units of penetration to indicate hundredths of a centimeter.

Penetration Method.† The method of constructing a bituminous macadam pavement by pouring or grouting the bituminous material into the upper course of the road material before the binding of the latter has been completed.

Petroleum.‡ Liquid bitumen occurring as such in nature.

Petrol Motor Roller (British *). Roller driven by internal combustion engine.

Pile.** A member usually driven or jetted into the ground and deriving its support from the underlying strata, and by the friction of the ground on its surface.

Pin Knot.* A pin knot is a sound knot not over ½ in in diameter.

Pitch.†* Solid residue produced in the evaporation or distillation of bitumens, the term being usually applied to the residue obtained from tar.

Hard Pitch.† Pitch showing a penetration of not more than 10.

Soft Pitch.† Pitch showing a penetration of more than 10.

Pitch (British †) is the solid or semi-solid residue from the partial evaporation or distillation of tar.

Pitch Grouting, Double (British *). Two separate coats of macadam, each separately grouted with a mixture of pitch, tar, and sand.

Pitch Grouting, Single (British *). A single layer of macadam grouted with a mixture of pitch, tar, and sand.

Pitch Pockets.* Pitch pockets are openings between the grain of the wood containing more or less pitch or bark. These shall be classified as small, standard and large pitch pockets.

SMALL PITCH POCKET. A small pitch pocket is one not over ⅛ in wide.

STANDARD PITCH POCKET. A standard pitch pocket is one not over ⅜ in wide, or 3 in in length.

LARGE PITCH POCKET. A large pitch pocket is one over ⅜ in wide, or over 3 in in length.

Pitch Streak.* A pitch streak is a well-defined accumulation of pitch at one point in the piece. When not sufficient to develop a well-defined streak, or where the fiber between grains, that is, the coarse-grained fiber, usually termed spring wood, is not saturated with pitch, it shall not be considered a defect.

Pith Knot.* A pith knot is a sound knot with a pith hole not more than ¼ in in diameter in the center.

Plutonic Rocks. Rocks which were formed by the cooling of molten mineral matter before it reached the surface.

Pocket.† A hole or depression in the wearing course.

Pointing.** Filling joints or defects in the face of a masonry structure.

Porphyritic. A textural term used to describe a compact structure thruout which there are large crystals.

Porphyry. Rock consisting of a very fine grained or micro-crystalline ground-mass thru which are disseminated distinctly recognizable crystals of some mineral.

Portland Cement.** This term shall be applied to the finely pulverized product resulting from the calcination to incipient fusion of an intimate mixture of properly proportioned argillaceous and calcareous materials, and to which no addition greater than 3% has been made subsequent to calcination.

Pot-Hole.† A hole extending below the wearing course.

Precast Concrete.†† Concrete which is cast into forms and then hoisted and set in place.

Profile.† A longitudinal section of a highway, generally taken along the center line.

Puzzolan Cement, as made in North America.** An intimate mixture obtained by finely pulverizing together granulated basic, blast furnace slag and slacked lime.

Quarters.† The four sections of equal width which, side by side, make up the total width of a roadway.

Quarters (British*). If the cross-section of a carriageway is divided into four equal portions, the outside portions are termed quarters.

Rack (British ‡). To fill in the joints between stone setts or wood blocks with fine, sharp gravel or chippings before grouting.

Ramp.** An inclined approach.

Raveling.† The loosening of the metal composing the crust.

Refined Asphalt.‡‡ Asphalt which has been subjected to a refining process but which is ordinarily too hard for use in the manufacture of

bituminous pavements until softened by combining it with a flux. Note: Commonly designated in paving work as R. A.

Refined Tar.†* A tar freed from water by evaporation or distillation which is continued until the residue is of desired consistency, or a product produced by fluxing tar residuum with tar distillate.

Refuge (British *). Raised platform in middle of roadway for safety of foot passengers.

Reinforced Concrete.†† Concrete in which metal, generally steel, has been embedded in proportionately small sections in such a manner that the metal and the concrete assist each other in taking stress.

Reinforcement.†† The metal, generally steel, embedded in concrete in proportionately small sections in such a manner that the two materials assist each other in taking stress.

Renewals.† Extensive repairs over practically the whole surface of the metaled or paved portion of the highway.

Repairs.† The restoration or mending of a considerable amount of the metaled or paved portion of the highway, but not usually of a majority of the surface area. More extensive than Patching, but less so than Renewals.

Residual Petroleum.‡‡ A liquid residue obtained by distilling petroleum to a point beyond which water and oils accompanying the elimination of water are removed.

Resurfacing.† The renewal of the surface of the crust or pavement.

Rhyolite.* Volcanic rocks of porphyritic or felsitic texture, whose phenocrysts are prevailingly orthoclase and quartz, less abundantly biotite, hornblende, or pyroxene, and whose groundmass is crystalline, glassy, or both.

Riddle (British ‡). A sieve, generally constructed with wire meshes.

Ring.** A metal hoop used to bind the head of a pile during driving.

Ring Shake.* An opening between the annual rings.

Ring Stones.** The end voussoirs of an arch.

Riprap.** Rough stone of various sizes placed compactly or irregularly to prevent scour of water.

Road.† A highway outside of an urban district.

Road-Bed.† The natural foundation of a roadway.

Road Crust (British *). See Wearing Surface.

Road Edge (British *). Verge, kerb, grass edge.

Road Metal.† Broken stone, gravel, slag, or similar material used in road and pavement construction and maintenance.

Roadway.† That portion of a highway particularly devoted to the use of vehicles.

Rock Asphalt.†‡ Sandstone or limestone naturally impregnated with asphalt.

Rock Asphalt Pavement.† A wearing course composed of broken or pulverized rock asphalt with or without the addition of other bituminous materials.

Rock-Faced.** Presenting irregular projecting face, without indications of tool mark.

Roller, Heavy (British *). Roller over 6 tons in weight.

Roller, Light (British *). Roller under 6 tons in weight.

Rough Pointed.** Having irregular surface, the variations of which do not exceed ½ in from the pitch line.

Rot, Dote and Red Heart.* Any form of decay which may be evident

either as a dark red discoloration not found in the sound wood, or the presence of white or red rotten spots, shall be considered as a defect.

Rotten Knot.* A rotten knot is one not as hard as the wood it is in.

Round Knot.* A round knot is one which is oval or circular in form.

Rubble.** Field stone or rough stone as it comes from the quarry. When it is of a large or massive size it is termed block rubble.

Rubble.* Rough stones of irregular shapes and sizes, broken from larger masses, either naturally or artificially, as by geological action, in quarrying or in stone-cutting or blasting.

Rubble (British *). Any disintegrated rock found *in situ*.

Rubble or Cyclopean Concrete.†† Concrete in which large stones are embedded after mixing and during placing.

Sand.† Finely divided rock detritus, the particles of which will pass a 10-mesh and be retained on a 200-mesh screen.

Sand-Clay Road.† A roadway composed of an intimate mixture of sand and clay.

Sandstone. Rock formed by the consolidation of sand.

Sapwood.** A cylinder of wood next to the bark and of lighter color than the wood within. It may be of uneven thickness.

Scabbled.** Having irregular surface, the variations of which do not exceed ¾ in from the pitch line.

Scarify.† To loosen and disturb superficially.

Scavenge (British*). To clean.

Schist. Thinly laminated, metamorphic rocks which split more or less readily along certain planes approximately parallel and differing from the gneisses principally in the lack of feldspar.

Schistose. A textural term used to describe a rock structure which has a tendency to split along lines of stratification.

Scores (British ‡). Faint ruts or marks on the surface of a carriageway.

Screen.†‡ In laboratory work, an apparatus, in which the apertures are circular, for separating sizes of material.

Screenings.† Broken rock, including the dust, of a size that will pass thru a ½ to ¾-in screen, depending upon the character of the stone.

Seal Coat.† A final superficial application of bituminous material during construction to a bituminous pavement.

Seepage. Quiet emergence of water along some rather extensive line or surface, as contrasted with a spring whose water emerges from a single spot (see Sect. 3, Art. 12).

Sett (British*). Stone block.

Setting Up.† As applied to bituminous material, the relative quick change which takes place after its application to a roadway, indicated by its hardening after cooling and exposure to atmospheric and traffic conditions, as opposed to the slower changes later occurring gradually and almost imperceptibly.

Shakes.* Shakes are splits or checks in timbers which usually cause a separation of the wood between annual rings.

Shaping.† Trimming up and preparing a subgrade preparatory to applying the first course of the road metal or artificial foundation

Sheet-Asphalt Pavement.† One having a wearing course composed of asphalt cement and sand of predetermined grading, with or without the addition of fine material, incorporated together by mixing methods.

Sheet Pavement.† A pavement free from frequent joints such as would

accompany small slabs or blocks, and which has an appreciable thickness, say in excess of 1 in on the average, for its wearing course.

Sheet Piles.** Piles driven in close contact in order to provide a tight wall, to prevent leakage of water and soft materials; or driven to resist the lateral pressure of adjacent ground.

Shingle (British ‡). Round, water-worn, loose gravel and pebbles.

Shoe.** A metal protection for the point or foot of a pile.

Shoulders.† The portion of the highway between the edges of the road metal or pavement and the gutters, slopes, or water-courses.

Side-Drainage.† That along the sides of the roadway.

Sidewalk.† The portion of the highway reserved for pedestrians.

Sieve.†‡ In laboratory work, an apparatus, in which the apertures are square, for separating sizes of material.

Silt.† Naturally deposited fine earthy material, which will pass a 200-mesh sieve.

Skid-Pan (British ‡). A shoe or drag used on wheels when descending hills.

Slag.‡† Fused or partly fused compounds of silica in combination with lime or other bases, resulting in secondary products from the reduction of metallic ores.

Slope Wall.** A wall to protect the slope of an embankment or cut.

Slope Stakes.** Stakes set to indicate the top or bottom of a slope.

Smooth.** Having a surface, the variations of which do not exceed $\frac{1}{8}$ in from the pitch line.

Snow Fence.** A structure erected for the purpose of forming artificial eddies on the windward side of a cut at sufficient distance away to cause snow to deposit between the snow fence and the cut.

Soil.* A mixture of fine earthy material, with more or less organic matter, resulting from the growth and decomposition of vegetable or animal matter.

Sound Knot.* A sound knot is one which is solid across its face and which is as hard as the wood surrounding it; it may be either red or black, and is so fixed by growth or position that it will retain its place in the piece.

Spall.** A chip or small piece of stone broken from a large block.

Spalls.† Fragments broken off by a blow, irregular in shape, and of sufficient size to be comparable to the original mass.

Spandrel Wall.** The wall at the end of an arch above the springing line and extrados of the arch and below the coping or the string course.

Springwood.** The inner part of the annual ring formed in the earlier part of the season, not necessarily in the spring, and often containing vessels or pores.

Spike Knot.* A spike knot is one sawn in a lengthwise direction; the mean or average width shall be considered in measuring these knots.

Squeegee.† A tool with a rubber or leather edge for scraping or cleaning hard surfaces, or for spreading and distributing liquid material over and into the superficial interstices of roadways.

Squeegee Coat.† An application by means of the squeegee.

Standard Knot.* A standard knot is a sound knot not over $1\frac{1}{2}$ in in diameter.

Steam Hammer.** One which is automatically operated by the action of a steam cylinder and piston supported in a frame which rests on the pile.

Stirrup.†† A piece of metal reinforcement placed in a beam in order to resist tensile stresses in the concrete set up by a combination of shear and longitudinal tension.

Stone Block Pavement.† One having a wearing course composed of stone blocks quite or nearly rectangular in shape.

Stone Chips.* Small angular fragments of stone containing no dust.

Straight-Run Pitch.* A pitch run to the consistency desired, in the initial process of distillation, without subsequent fluxing.

Stratified. A textural term used to describe a rock structure composed of parallel layers.

Street.† A highway in an urban district.

Strength Crust (British*). See subcrust

Stretcher.** A stone which has its greatest length parallel to the face of the wall.

Subcrust (British*). Intermediate formation between the foundation and the wearing surface.

Sub-Drain.** A covered drain, below the road-bed or ground surface, receiving the water along its length by absorption or thru the joints.

Sub- or Under-Drainage.† That below the surface.

Subgrade.† The upper surface of the native foundation on which is placed the road metal or the artificial foundation, in case the latter is provided.

Subsoil (British *). Nature of the ground on which the foundations are laid.

Summerwood.** The outer part of the annual ring formed later in the season, not necessarily in the summer, being usually dense in structure and without conspicuous pores.

Supercrust (British*). See Wearing Surface.

Superficial Coat.† A light surface coat.

Surcharged Wall (British *). Retaining wall of bank which slopes backwards to a higher level.

Surface Coat.† See Carpet.

Surface Drainage.† That on the roadway or ground surface.

Surface-Sealing (British ‡). The final operation of closing and making waterproof the surface of a carriageway with a bituminous compound.

Surface Treatment.† Treating the finished surface of a roadway with bituminous material.

Surfacing.† (1) The crust or pavement. (2) Constructing a crust or pavement. (3) Finally finishing the surface of a roadway. (4) Treating the surface of a finished roadway with a bituminous material.

Syenite. Granitoid rocks consisting of orthoclase, hornblende, biotite, and augite.

Tailings.†* Stones, which after going thru the crusher, do not pass thru the largest openings of the screen.

Tar.†* Bitumen which yields pitch upon fractional distillation and which is produced as a distillate by the destructive distillation of bitumens, pyro-bitumens, or organic material.

Tar (British†) is the matter, freed from water, condensed from the volatile products of the destructive distillation of hydrocarbon matter, whether this be contained in coal, wood, peat, oil, etc. A prefix such as Coal, Wood, Peat, Gas Works, Blast Furnace, Coke Oven, etc, must be added to the word Tar to indicate the source of origin or method of production.

Tar Concrete Pavement. One composed of broken stone, broken slag, gravel or shell, with or without sand, Portland cement, fine inert material, or combinations thereof, and a tar cement incorporated together by a mixing method.

Tar Macadam Pavement. One having a wearing course of macadam with the interstices filled by a penetration method with a tar binder.

Tar Spraying (British *). Spreading tar on road surface.

Tar Washing (British *). See Tar Spraying.

Telford.† Properly, an artificial foundation advocated by Thomas Telford (1757–1820), and consisting of a pavement of stone about 8 in thick, laid by hand, and closely packed and wedged together. The individual stones were desired to be about 16 sq in in section, and about 8 in in length. They were placed close together on the prepared subgrade, their longest dimension vertical and on their larger ends, their interstices chinked with smaller stones, and the whole rammed, or rolled, until firm and unyielding.

Telford Macadam.† Macadam with an artificial foundation of Telford.

Trap Rock. A very general term, little employed in scientific language but commonly used to designate dense and generally fine-grained igneous rocks of black or dark green color. The term is almost synonymous with basalt or diabase but might include as well, gabbro, norite, peridotite, pyroxenite, etc. When altered, such rocks assume a green color from hornblende, chlorite, epidote, or other secondary minerals developed in them, and they are then known as greenstone. Both greenstone and trap would include a wide range of rock families which by reason of their fine texture and altered condition are difficult to determine without careful and generally microscopic study. (The New International Encyclopædia).

Thru Shake.* A shake which extends between two faces of a timber.

Tile (British *). Baked brick of fine clay.

Timber Platform (British *). Platform of timber for foundations on marshy soil.

Timbers.* The classification of structural timbers is as follows:

Douglas Fir.* The term Douglas Fir is to cover the timber known likewise as yellow fir, red fir, western fir, Washington fir, Oregon or Puget Sound fir or pine, northwest and west coast fir.

Hemlock,* to cover southern or eastern hemlock; that is, hemlock from all states east of and including Minnesota.

Idaho White Pine,* the variety of white pine from western Montana, northern Idaho, and eastern Washington.

Norway Pine,* to cover what is known also as Red Pine.

Redwood,* to include the California wood usually known by that name.

Spruce,* to cover eastern spruce; that is, the spruce timber coming from points east of and including Minnesota.

Southern Yellow Pine.* This term includes the species of yellow pine growing in the southern states from Virginia to Texas, that is, the pines hitherto known as long-leaf pine, short-leaf pine, loblolly pine, Cuban pine and pond pine. Under this heading, two classes of timber are designated: (1) dense southern yellow pine and (2) sound southern yellow pine. It is understood that these two terms are descriptive of quality rather than of botanical species.

1. Dense southern yellow pine shall show on either end an average of at least 6 annual rings per in and at least one-third summer wood, or else the greater number of the rings shall show at least one-third summer wood, all as measured over the 3rd, 4th, and 5th in on a radial line from the pith. Wide-ringed material excluded by this rule will be acceptable, provided that the amount of summer wood as above measured shall be at least one-half. The contrast in color between summer wood and spring wood

shall be sharp and the summer wood shall be dark in color, except in pieces having considerably above the minimum requirement for summer wood.

2. Sound southern yellow pine shall include pieces of southern pine without any ring or summer wood requirement.

TAMARACK,* to cover the timber known as Tamarack, or eastern Tamarack, from states east of and including Minnesota.

WESTERN HEMLOCK,* to cover hemlock from the Pacific coast.

WESTERN LARCH,* to cover the species of larch or tamarack from the Rocky Mountain and Pacific coast regions.

WESTERN PINE,* to cover the timber sold as white pine coming from Arizona, California, New Mexico, Colorado, Oregon and Washington. This is the timber sometimes known as western Yellow Pine, Ponderosa Pine, California White Pine, or western White Pine.

WESTERN SPRUCE,* to cover the spruce timber from the Pacific coast.

WHITE PINE,* to cover the timber which has hitherto been known as white pine, from Maine, Michigan, Wisconsin and Minnesota.

Tooling.†† The finishing of concrete surfaces with special hand or power tool producing a surface which will show the lines of the tool.

Topped Petroleum.‡ Petroleum deprived of its more volatile constituents.

Toughness. The property of resistance to breaking by impact.

Tracking (British ‡). A term applied to designate traffic which follows the same course, and consequently forms ruts. The term is also sometimes applied to the act of repairing the tracks thus caused.

Traffic (British ‡). A term applied to the amount of use of a road. Light traffic has been held to mean about 70 vehicles a day, including an occasional traction engine or heavy motor; medium traffic from 70 to 250 vehicles, including not more than 5% of traction engines or heavy motors; heavy traffic, from 250 to 600 vehicles, of which 5 to 10% is traction engines or heavy motors; very heavy traffic exceeds this.

Transverse Balancing (British *). Locating the center of a road in a hilly district so that the cutting on one side forms the enbankment on the other.

Traveler.†† A temporary structure, usually of steel but sometimes of wood, which is employed to raise into position the structural members of a bridge or other structure and which in itself is so constructed that it can move backward and forward in accordance with the progress of the work.

Twisted Bar.†† A steel bar which has been twisted either before or after cooling in order to raise its elastic limit. Bars twisted before cooling are known as hot twisted and those twisted after cooling are known as cold twisted.

Tynes (British *). Teeth of scarifier.

Up-Keep.† Maintenance.

V-Drainage.† That provided by the construction of troughs in the subgrade of the roadway, which troughs are like a V, with flat sloping sides, and are filled with stone.

Verge (British*). Edge, grass edge, green sward.

Viagraph (British ‡). An instrument for measuring the inequalities of a carriageway surface.

Viscosity.†‡ The measure of the resistance to flow of a bituminous material, usually stated as the time of flow of a given amount of the material thru a given orifice.

Volatile.† Applied to those fractions of bituminous materials which will evaporate at climatic temperatures.

Volcanic Rocks. Rocks which have been formed by mineral matter erupted in a molten condition and cooled on the surface.

Voussoirs.** The individual stones forming an arch. They are always of truncated wedge form.

Wane.* Wane is bark, or the lack of wood from any cause, on edges of timbers.

Waste.** Material from excavation not used in the formation of the roadway.

Waste or Spoil Banks.** Banks outside the roadway formed by waste.

Water-Bound.† Bound or bonded with the aid of water.

Water-Gas Tars.*† Tars produced by cracking oil vapors at high temperatures in the manufacture of carburetted water-gas.

Water Tables (British *). See Channels.

Wearing Coat.† The superficial layer of the crust or pavement exposed to traffic.

Wearing Course.† The course of the crust or pavement exposed to traffic.

Wearing Crust (British*). Uppermost surface of roadway.

Wearing Surface (British*). Renewable surface of road in contact with traffic.

Well or Sump.** A cistern or well into which water may be conducted by ditches to drain other portions of a piece of work.

Wheelers (British ‡). A term applied to stone blocks laid parallel to the kerb in a street to take the wheels of heavy traffic.

Whinstone (British*). Greenstone, dark green igneous rocks.

Wing Wall.** An extension of an abutment wall to retain the adjacent earth.

Wire Fabric.†† A form of concrete reinforcement composed of parallel longitudinal wires tied together at intervals by transverse wires. The intersecting wires are sometimes welded together. Also known as Wire Cloth or Wire Mesh.

Wood Block Pavement.† One having a wearing course composed of wood paving blocks, generally rectangular in shape.

3. Reports Pertaining to the British Terminology of Bituminous Materials

Introductory Remarks of the Engineering Standards Committee of Great Britain (15) pertaining to the "British Standard Nomenclature of Tars, Pitches, Bitumens and Asphalts, when Used for Road Purposes."

"The materials now used by Road Engineers for binding together the stones and other mineral aggregate used to form road crusts and road surfaces may be conveniently divided into three groups. These are:

1. The tars and pitches obtained by the destructive distillation of coal or similar substances.
2. The bitumens and asphalts which are found in nature, or are obtained artificially from asphaltic oils.
3. Chemical binders, including the Portland and natural cements, which owe their cementing value as road binders to chemical action, and which are not dealt with in the present report.

"Hitherto the term bituminous material has been loosely applied to tar products as well as bitumens and asphalts, but the Committee have from the first considered that it was desirable from the Road Engineers' point of view to maintain a sharp line of demarcation between the two groups. The views put forward in correspon-

dence from America and by American engineers of standing and experience have been carefully considered, but the Committee still adhere strongly to the view that the description bituminous should be applied only to the second group.

"The Committee have been very anxious to secure uniformity with American practice, and have carefully and fully considered the definitions adopted by the Am. Soc. Test. Mat. and by the Committee of the Am. Soc. C. E., put forward by the American corresponding members, but it is felt that the definitions now decided on are preferable from the Road Engineers' point of view, as they are based on those characteristics of the materials which can be most readily verified when employed for road making.

"In accordance with this view the Committee consider that it is desirable to make a sharp distinction between coal tar and paraffin oil derivatives on the one side, and native bituminous substances and asphaltic oil residues on the other, and they are therefore unable to accept the American definition of Bitumen which would include the coal tars."

1917 Report (12c) of Com. D-4 on Road Materials, Am. Soc. Test. Mat. relative to the report and definitions of bituminous materials of the Engineering Standards Committee of Great Britain (15).

"It is evident that the basic difference between the British and American nomenclature has to do with the term bitumen. The Am. Soc. Test. Mat. standard definition includes all mixtures of native or pyrogenous hydrocarbons and their non-metallic derivatives which are soluble in carbon disulphide. It thus includes the carbon disulphide soluble constituents of tars as well as of petroleums and asphalts. The British definition eliminates tars by including only native hydrocarbon products or those obtained by the evaporation of asphaltic oils. The American definition is sufficiently broad to make it perfectly possible to determine the actual percentage of bitumen in bituminous materials, while the British definition is absolutely valueless in this respect. As an example, the British definition, while including a refined native asphalt fluxed with an asphaltic petroleum residuum, would exclude, so far as analytical methods of determination are concerned, the same asphalt fluxed with a paraffin or semi-asphaltic flux. To sum up the foregoing discussion, Com. D-4 believes that the British definition of bitumen is much less useful than the definition adopted by the Am. Soc. Test. Mat., which is definite, consistent, and logical.

"Com. D-4 has no comment to make upon the British definition of Native Bitumen, as the interpretation of the definition is largely dependent upon the meaning of the word bitumen, which has already been discussed.

"The British definition of asphalt, aside from its dependence upon the meaning of the word Bitumen is entirely foreign to the American usage of the term and to the American point of view. This definition coincides with the American idea of a fine-graded bituminous aggregate and includes both the bituminous cement and the mineral particles. It is thus seen in the definition of the Engineering Standards Committee that Native Asphalt is synonymous with Rock Asphalt. It should be noted that the latter definition entirely eliminates our oldest and most widely used native asphalts while the definition of asphalt eliminates all of our oil or petroleum asphalts and such products as Gilsonite and even refined Bermudez Asphalt. The differences are evidently those of long established custom in both countries, and in view of this fact are apparently irreconcilable.

"The British definition of tar, while worded somewhat differently, is almost the same as the American definition except that it is not considered to be bitumen, which difference has already been discussed under Bitumen. Aside from this, Com. D-4 believes the American definition to be more specific and accurate, inasmuch as it limits the term Tar to hydrocarbon products produced by destructive distillation which, when subjected to fractional distillation, will yield pitch. It thus eliminates such volatile substances by themselves as benzol, toluol, etc, altho these constituents may form a part of the tar.

"The British definition of pitch is practically the same as the American except that the former limits the term specifically to semisolid or solid tar residues, while the latter includes solid residues from any bitumen, but states that the term is usually applied to residues obtained from tars. Com. D-4 believes that there is but little choice between the two as to all intents and purposes they answer the same purpose. Attention is, however, called to the British lack of distinction between the words

evaporation and distillation which are apparently used synonymously thruout the British nomenclature.

"Com. D-4 is heartily in accord and strongly indorses the recommendations of the Engineering Standards Committee regarding the use of prefixes. In fact, as the result of its efforts and the recommendations of the main Committee it might be noted that the Am. Soc. Test. Mat. has even gone to the extent of defining certain classes of bituminous materials as indicated by prefixes suggested by the Engineering Standards Committee."

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SECTION 2

MATHEMATICS, MECHANICS AND STRUCTURAL MATERIALS

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MATHEMATICS*

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STRUCTURAL MATERIALS

1. Algebra

A Linear Algebraic Equation in one unknown is solved by collecting the unknown quantities on one side of the equation, the known quantities on the other side, and by dividing both sides of the equation by the coefficient of the unknown. Thus $4x - x = 6 - 5x$, may be written $4x - x + 5x = 6$ or $8x = 6$; hence $x = 3/4$.

Systems of Linear Equations. A system of two equations with two unknowns can be solved as follows: Given the equations, $a_1 x + b_1 y = c_1$ and $a_2 x + b_2 y = c_2$; where a_1, a_2, b_1, b_2, c_1 and c_2 are constants, the values of x and y which satisfy the equations can be obtained by substituting in the second equation, the value of x, obtained by solving the first equation for x in terms of y and the constants, and solving the equation thus formed for y; or the two equations may be solved by multiplying the first equation by the coefficient of x in the second equation, and the second equation by the coefficient of x in the first equation, and since x may be eliminated by subtracting one equation from the other, the resulting equation may be solved for y. A system of three linear equations can be solved in a similar manner. For methods of solving linear equations by the aid of determinants, see (35) and (60).

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Quadratic Equations. A complete quadratic equation in one unknown quantity is of the form $ax^2 + bx + c = 0$, where a, b, c are constants. In such an equation there are two roots, that is, two values of the unknown that will satisfy the equation. If x_1 is one of these roots and x_2 the other, their value in terms of a, b, c are,

$$\left.\begin{aligned} x_1 &= \frac{-b + \sqrt{b^2 - 4ac}}{2a} \\ x_2 &= \frac{-b - \sqrt{b^2 - 4ac}}{2a} \end{aligned}\right\} \quad (1)$$

The expression b^2-4ac is called the discriminant of the equation. By means of the discriminant, the character of the roots of any quadratic equation can be determined without actually solving the equation, provided a, b, c are real numbers.

If $b^2 - 4ac = 0$, the roots are real and equal.

If $b^2 - 4ac < 0$, both roots are imaginary.

If $b^2 - 4ac > 0$, the roots are real and unequal. In the last case they are rational if $b^2 - 4ac$ is a perfect square, irrational if it is not a perfect square.

A System of Two Equations with two unknowns, when one of the equations, at least, is of a degree higher than the first, in many cases is easily solved. No general method of solution applicable to all cases can be given. Perhaps the case that occurs most often is the one where one equation is of the first degree and the other is of the second. Such a system can be solved as follows: From the linear equation find the value of one unknown in terms of the other. Substitute this expression for the first unknown in the second degree equation and the result will be a quadratic in the second unknown. The roots of this quadratic can be found by formulæ (1). These values substituted in either equation will give the corresponding values of the first unknown.

For more special methods, see (15), (29) and (45). In all cases, the final results should be checked by substituting them in both equations to determine whether they satisfy the equations. If a pair of values are found that do not satisfy the equations, they are not roots of the equations and cannot be used.

The Logarithm of a Number is the exponent that indicates the power to which a given fixed quantity, called the BASE of the system of logarithms, is raised to produce the number. There are two systems of logarithms in common use, the Naperian or natural system and the Briggs or common system. The Naperian system is used mainly in theoretical work. Its base is designated by the letter e and is equal to 2.7182818. . . . The Briggs system is commonly used in computations, and its base is 10. The discussion here will apply only to the Briggs system.

Since few numbers are exact multiples of ten, a logarithm generally is composed of two parts, the integral part and the decimal part. The integral part is called the CHARACTERISTIC, and the decimal part, the MANTISSA. The characteristic of a logarithm may be either positive or negative. The mantissa is always positive. Common logarithms are used in finding products, quotients, powers and roots of numbers. The logarithm of a product is equal to the sum of the logarithms of the several factors composing the product. The logarithm of a quotient is equal to the logarithm of the dividend minus the logarithm of the divisor. The logarithm of the power of a quantity is equal to the logarithm of the quantity

multiplied by the index of the power. The logarithm of the root of a quantity is equal to the logarithm of the quantity divided by the index of the root.

LOGARITHMIC TABLES generally contain only mantissas of logarithms. The characteristic can be found by the following rule: The characteristic of the logarithm of a number greater than unity is positive, that of a number less than unity is negative. Assuming the number to be written in the form of a mixed decimal, the number of units in the characteristic is equal to the number of places the first significant figure in the number is removed from the units place.

For example, log 345.2 = 2.53807; log 0.003452 = $\bar{3}$.53807 or 7.53807 − 10. It will be noticed that the magnitude of the characteristic is determined by the position of the decimal point alone, and that the mantissa is affected only by the particular figures in the number and by the order in which they are arranged.

2. Graphs

Coördinates of a Point. The position of a point in a plane is determined definitely if there are given its distances from two arbitrary straight lines drawn perpendicular to each other in the plane. The two lines are called the x- and y-axes, or the axes of coördinates. The point of intersection of the axes is called the origin. The distance of a point from the y-axis measured parallel to the x-axis, is called its x-distance or ABSCISSA. The distance of a point from the x-axis, measured parallel to the y-axis, is called its y-distance or ORDINATE. The two distances together are called its COÖRDINATES. If the coördinates of a point P are $x = a$ and $y = b$, they are written $P \equiv (a, b)$. Abscissas measured to the right of the y-axis are positive, those measured to the left are negative. Ordinates measured up from the x-axis are positive, those measured down are negative.

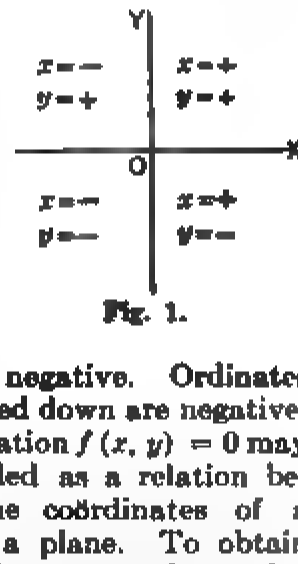

Fig. 1.

An equation $f(x, y) = 0$ may be regarded as a relation between the coördinates of a point in a plane. To obtain the simultaneous values of x and y that will satisfy the equation, it is customary to substitute certain values for x in the equation and compute the corresponding values of y. If the points, whose coördinates are simultaneous values of x and y, are plotted with respect to a pair of coördinate axes, and a curve is drawn thru successive points, a figure is obtained which is a graphical representation of the function. To obtain a figure of correct proportions, the units on both axes should be the same.

Fig. 2.

Example 1. Given $x^2 + y^2 = 25$. Then, $y = \pm\sqrt{25 - x^2}$. Corresponding values of the variables are,

$x = 0$ 1	2	3	4	5	-1	-2	-3	-4	-5
$y = \pm 5$ .... ± 4.9	± 4.6	± 4	± 3	0	4 9	± 4 6	± 4	3	0

The curve is shown in Fig. 2.

Example 2. Given $y = \log_{10} x$. Corresponding values of the variables are,

$x = 0$	0 5	1	2	3	4	5
$y = -\infty$	-0 3	0	0.3	0.5	0.6	0.7

The curve is shown in Fig. 3.

In practical work graphs are used to show more clearly than numbers the relation between corresponding tables of values found often from observation. This method is especially valuable in the case of profiles. In such cases the units used on the axes generally are not the same.

The following data, found by the method of levelling, and the corresponding curve represent a portion of the profile of a street (see Fig. 4).

Fig. 3

Elevations

Fig. 4

Distances

Distance in Feet	Elevation	D	E	D	E	D	E
0	90.0	250	75.9	500	67 2	750	70.6
50	87.8	300	73.1	550	68.5	800	71.5
100	82.5	350	69.9	600	67.9	850	73.2
150	80.7	400	69.4	650	71.7	900	77.0
200	80.6	450	68.6	700	69.0	950	78.5

Equations of Curves. Frequently, it is desirable to obtain an equation which will represent the curve traced by a point moving according to some known law. Sometimes the equation may be written when the properties of the curve are known.

Example. The angle between the x-axis and a straight line, at every point of the line, is the same.

Hence, $\tan \gamma = \dfrac{y - y_1}{x - x_1} = \dfrac{y_2 - y_1}{x_2 - x_1}$

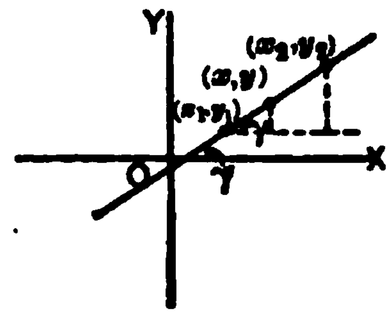

Fig. 5.

In other cases, the equation of the curve may be derived when the laws of motion of the point are known.

Example. A point moves so that its distance from a fixed point is always equal to its distance from a fixed straight line. Let the y-axis be the fixed straight line and let the fixed point be on the x-axis at a distance m from the origin. Then $P_1 P = N P$. That is, $\sqrt{(x - m)^2 + y^2} = x$, or $x^2 - 2mx + m^2 + y^2 = x^2$, hence, $y^2 = 2mx - m^2$, the equation of motion of the point.

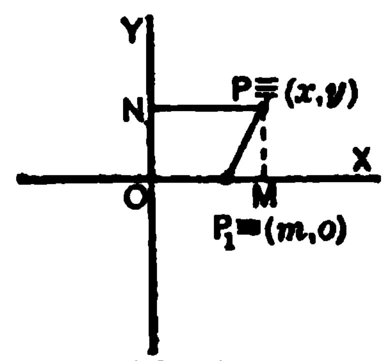

Fig. 6.

3. Geometry and Mensuration

Polygons. The area of a triangle will be treated in Art. 4. The area of a parallelogram is equal to the product of the base by the altitude. That is, $A = BH$. The area of any polygon, which is bounded by straight lines, may be found as follows: Divide the polygon into a number of triangles; find the area of each triangle; the area of the polygon is equal to the sum of the areas of the triangles. In the case of a regular polygon, this process is much simplified from the fact that a regular polygon has equal sides and equal angles. If one side is known, all are known. The angles also can be determined. In any plane polygon, the sum of the interior angles of the polygon formed by its sides is equal to $(n - 2)$ $180°$, where n is the number of sides of the polygon. Hence, in a regular polygon, each angle in degrees is equal to $\dfrac{(n - 2)\ 180°}{n}$.

Circles. Let R = radius, A = area. Then $A = \pi R^2$. Circumference $= 2\pi R$ when $\pi = 3.14159\ldots$ or, less accurately, $\dfrac{22}{7}$.

A SECTOR is the portion of a circle bounded by two radii and their intercepted arc. If O is the angle of the sector expressed in radians, the area of the sector is $A = \frac{1}{2} R^2 O$. A SEGMENT is the portion of a circle bounded by a chord and its subtended arc. The area of a segment is the difference between the area of the corresponding sector and that of the isosceles triangle formed by the chord of the segment and the two radii drawn to the extremities of the chord.

A Parallelopiped is a solid whose bounding surfaces are planes and whose opposite faces are parallel. All the faces of a parallelopiped are parallelograms. A RECTANGULAR PARALLELOPIPED is one whose bounding surfaces are all rectangles and therefore perpendicular to each other. A CUBE is a rectangular parallelopiped whose faces are equal squares. The surface of a parallelopiped is equivalent to the sum of the areas of the parallelograms forming its faces. If V = volume, B = area of base, H = altitude of any parallelopiped, $V = BH$.

Prisms. A prism is a solid whose bases are parallel polygons and whose lateral faces are parallelograms. The lateral faces of a prism intersect in lines called the edges of the prism. A RIGHT PRISM is a prism whose edges are perpendicular to its bases.

The lateral surface of any prism is equal to the product of an edge by the perimeter of a right section. The volume of any prism is equal to the product of its base and altitude. That is, Vol. $= BH$ where B = area of base, H = altitude. In particular, the volume of a right prism is equal to the product of its base by one of its edges.

Cylinders. A cylindrical surface is the surface generated by a straight line which moves always parallel to a given straight line and one point of which traces a curve. The generating line, in one of its positions, is called an ELEMENT of the surface. A cylinder is a solid whose bases are in parallel planes and whose lateral surface is a closed cylindrical surface. A CIRCULAR CYLINDER is a cylinder whose bases are equal circles. A RIGHT CIRCULAR CYLINDER, or a cylinder of revolution, is a circular cylinder whose elements are perpendicular to its bases.

The lateral area of a right circular cylinder is equal to the product of the circumference of its base by an element. The volume of any cylinder is equal to the product of its base and altitude. Thus, if V = volume, B = area of base, H = altitude; $V = BH$. In particular, the volume of a right cylinder is equal to the product of its base by an element.

Pyramids. A pyramid is a solid whose base is a polygon and whose lateral surface is composed of triangles, all the vertices of which lie in one point which is called the VERTEX of the pyramid. A REGULAR PYRAMID is a pyramid whose base is a regular polygon and whose vertex is in the perpendicular drawn to the base at its middle point. It follows from this definition that the lateral surface of a regular pyramid is composed of equal isosceles triangles. The triangles composing the lateral surface of a pyramid are called its LATERAL FACES. The slant height of a regular pyramid is the ALTITUDE of one of its lateral faces.

The lateral surface of a regular pyramid is equal to one-half the product of the perimeter of its base and its slant height. If S = lateral surface, P = the perimeter of the base, L = slant height; $S = \frac{1}{2} PL$. The volume of any pyramid is equal to one-third the product of its base by its altitude. If V = volume, B = area of base, H = altitude; $V = \frac{1}{3} B H$.

The Frustum of a Pyramid is the portion of a pyramid included between its base and a plane parallel to its base which cuts all the lateral edges of the pyramid. The two parallel polygons thus formed are called the upper and lower bases of the frustum. The lateral faces of the frustum of a regular pyramid are equal isosceles trapezoids. The altitude of one of these trapezoids is called the slant height of the frustum. The lateral surface of the frustum of a regular pyramid is equal to the product of one-half the sum of the perimeters of its BASES multiplied by the slant height of the frustum. The volume of the frustum of a pyramid is equivalent to the sum of the volumes of three pyramids which have for their bases the bases of the frustum and a mean proportional between the bases of the frustum and which have for their common altitude the altitude of the frustum.

Cones. A conical surface is a curved surface generated by a moving straight line called the GENERATOR which continually touches a given curve and passes thru a fixed point called the VERTEX of the surface. The generator in any one of its positions is called an element of the surface. A cone is a solid whose lateral surface is a closed conical surface and whose base is a plane figure bounded by a curve. A CIRCULAR CONE is a cone whose base is a circle. A RIGHT CIRCULAR CONE, or a cone of revolution, is a circular cone whose vertex is in the perpendicular drawn to the center of the base.

The lateral surface of a right circular cone is equal to one-half the product of the circumference of its base and one of its elements. The volume of any cone is equal

to one-third the product of its base by its altitude. If B = area of base, H = altitude, V = volume of cone; $V = \frac{1}{3} BH$.

The Frustum of a Cone is the portion of a cone included between its base and a plane parallel to the base which cuts all the elements of the cone. The curved figures formed by the intersections of the parallel planes with the conical surface are called the BASES of the frustum. The portion of an element of a cone of revolution included between the two bases of the frustum is called the SLANT HEIGHT of the frustum. The lateral surface of the frustum of a cone of revolution is equal to the product of half the sum of the circumferences of its bases multiplied by its slant height. The volume of the frustum of a circular cone is equivalent to the sum of the volumes of three cones which have for their bases the bases of the frustum and a mean proportional between the bases of the frustum and for their common altitude the altitude of the frustum.

Spheres. A sphere is a solid bounded by a curved surface all points of which are equally distant from a point within called the center. A GREAT CIRCLE of a sphere is the section of a sphere made by a plane passing thru its center. A SMALL CIRCLE of a sphere is a section of a sphere made by a plane which does not pass thru the center of the sphere.

If V = volume of sphere, S = surface, R = radius; $V = \frac{4}{3} \pi R^3$ and $S = 4 \pi R^2$.

4. Plane Trigonometry

In a plane triangle let the angles be denoted by the letters A, B, C, and the sides opposite these angles by the corresponding small letters a, b, c.

Fundamental Relations among the trigonometric functions.

$$\sin^2 A + \cos^2 A = 1 \qquad \csc A = \frac{1}{\sin A}$$

$$\tan A = \frac{\sin A}{\cos A} \qquad \sec^2 A = 1 + \tan^2 A$$

$$\cot A = \frac{\cos A}{\sin A} \qquad \csc^2 A = 1 + \cot^2 A$$

$$\sec A = \frac{1}{\cos A} \qquad \tan A = \frac{1}{\cot A}$$

A Radian is the angle subtended at the center of a circle by an arc equal in length to the radius.

Functions of Any Angle. The functions of the complement of an angle are the co-functions of the angle. For example $\cos (90° - A) = \sin A$. To find the functions of angles greater than 90° in terms of an angle less than 90°, the following rule is convenient. The functions of $90° \pm A$ and of $270° \pm A$ are numerically equal to the co-functions of A and the functions of $-A$, $180° \pm A$, and $360° - A$ are numerically equal to the same functions of A. The algebraic sign to be placed before the result is determined by noting the sign of the function of the original angle in the quadrant in which that angle is located.

Examples. $\sin 200° = \sin (180° + 20°) = -\sin 20°$, since the sine of an angle between 180° and 270° is negative. $\cos 160° = \cos (90° + 70°) = -\sin 70°$, since the cosine of an angle between 90° and 180° is negative. This rule is important in the solution of some oblique triangles.

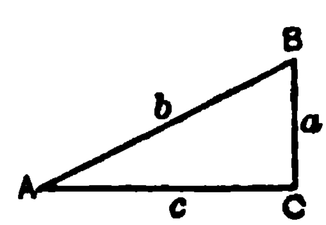

Fig. 7.

Right Triangles. Let C be the right angle and c, the hypotenuse. In order to solve the triangle, it is necessary to know, besides the right angle, two parts, of which one must be a side. Choose the particular trigonometric function, defined as the ratio of the sides of a right triangle, which contains the two given parts. From this function an unknown part of the triangle can be found.

· **Example.** Let a and A be given: $\sin A = \frac{a}{c}$ from which $c = \frac{a}{\sin A}$. Since $A + B = 90°$, $B = 90° - A$. Also $\frac{b}{c} = \sin B$. Therefore $b = c \sin B$. For a check use, $a^2 = c^2 - b^2 = (c + b)\ (c - b)$.

Oblique Triangles. LAW OF SINES. In any triangle, the sides of the triangle are proportional to the sines of the angles opposite. Stated in symbols the rule reads $\frac{\sin A}{a} = \frac{\sin B}{b} = \frac{\sin C}{c}$.

The law of sines is used in the solution of oblique triangles where two angles and a side are given, and where two sides and the angle opposite one of them are given. The latter is the so-called ambiguous case. Suppose A, b, a are given, the following possible cases may arise:

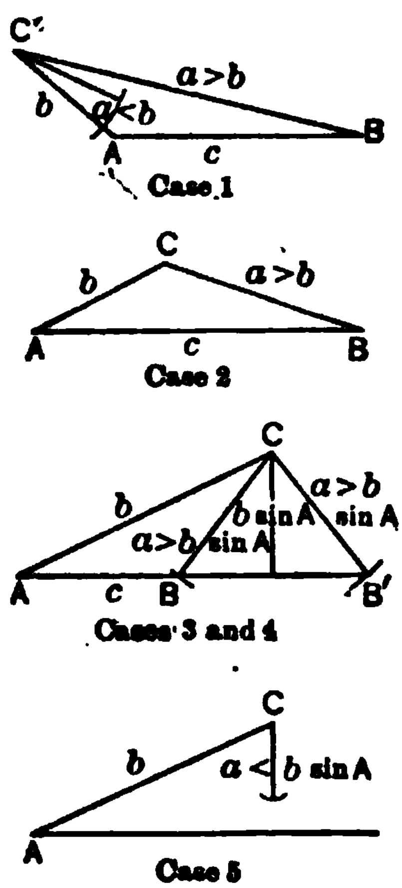

Fig. 8.

$A > 90°$, $b > a$, no solution. } Case 1.
$A > 90°$, $b < a$, one solution. }
$A < 90°$, $b < a$, one solution. Case 2.
$a < b\ A < 90°$, $a > b \sin A$, two solutions. Case 3.
$a < b\ A < 90°$, $a = b \sin A$, one solution. Case 4.
$a < b\ A < 90°$, $a < b \sin A$, no solution. Case 5.

In Case 3, in any engineering problem, it is likely that there will be sufficient data for the engineer to determine which of the two possible triangles is the one whose solution he desires.

THE LAW OF TANGENTS. In any triangle, the tangent of half the difference of the angles is to the tangent of half the sum, as the difference of the sides opposite is to their sum. That is,

$$\frac{\tan \frac{1}{2}(A - B)}{\tan \frac{1}{2}(A + B)} = \frac{a - b}{a + b}$$

or

$$\tan \tfrac{1}{2}(A - B) = \frac{a - b}{a + b} \tan \tfrac{1}{2}(A + B) \quad . \quad . \quad . \quad . \quad (1)$$

The law of tangents is used in the solution of an oblique triangle only in the case where two sides and their included angle are given. Suppose a, b, C are given and $a > b$. $A + B + C = 180°$. $\therefore \frac{1}{2}(A + B) = \frac{1}{2}(180° - C) = 90 - \frac{1}{2}C$. $\therefore$ Tan $\frac{1}{2}(A + B) = \tan (90° - \frac{1}{2}C)$. After computing the right hand side of formula (1), $\frac{1}{2}(A - B)$ is found from tables. Then,

$$\tfrac{1}{2}(A + B) + \tfrac{1}{2}(A - B) = A$$
$$\tfrac{1}{2}(A + B) - \tfrac{1}{2}(A - B) = B$$

Side c is then found by using the law of sines, that is, $c = \frac{a \sin C}{\sin A}$ or $c = \frac{b \sin C}{\sin B}$. By using both of these expressions to compute c, a check is obtained on all the work except the finding of log sin C.

THE LAW OF COSINES. The square of any side of a triangle is equal to the sum of the squares of the other two sides diminished by twice the product of those sides multiplied by the cosine of their included angle. That is,

$$a^2 = b^2 + c^2 - 2bc \cos A$$

The law of cosines can be used to compute the third side of a triangle when two sides and their included angle are given. It can be used also to find the angles of a triangle when the three sides are given. It should not be used for the latter purpose, however, when the angles to be found lie near 0° or 90°. The law of cosines is not adapted to the use of logarithms, so it is not advisable to use it unless the quantities given are simple numbers.

WHEN THREE SIDES OF A TRIANGLE are given, the angles can be found easily by the use of the formulas

$$\tan \tfrac{1}{2} A = \frac{v}{s - a}, \tan \tfrac{1}{2} B = \frac{v}{s - b}, \tan \tfrac{1}{2} C = \frac{v}{s - c} \quad . \quad . \quad (2)$$

where $$2s = a + b + c \text{ and } v = \sqrt{\frac{(s - a)(s - b)(s - c)}{s}}$$

When all the angles have been found in this way, a check is obtained from the fact that the sum of the angles of a triangle is equal to 180°, that is, $A + B + C = 180°$. When the law of sines, law of cosines, or law of tangents is used in the solution of a triangle, a complete check is obtained by finding one of the given angles by the use of one of formulas (2).

Area of a Triangle. When two sides and their included angle are given, say a, b, C: Area $= \tfrac{1}{2} ab \sin C$. When two angles and a side, say A, B, c, are given: Area $= \dfrac{c^2 \sin A \sin B}{2 \sin (A + B)}$. When three sides, a, b, c, are given: Area $= \sqrt{s(s - a)(s - b)(s - c)}$, where $2s = a + b + c$.

In computing the required parts of a triangle or its area, it is always better to use, so far as possible, the given parts. If this procedure is followed, previous errors of computation do not affect succeeding results. When this is not possible, great care should be taken to determine correctly parts that must be used in subsequent computations. Complete checks on all computations should be used.

5. Plane Analytic Geometry

Coördinate Axes in a plane are two arbitrary intersecting straight lines which, for practical purposes, are usually drawn perpendicular to each other. One line, the y-axis, is vertical, while the other, the x-axis, is horizontal. In the plane, the position of a point can be fixed by means of its distances from the two coördinate axes. This plane is called the xy-plane.

The Locus of a Point in a plane is the path traced by a point which moves in the plane according to certain laws.

THE EQUATION OF A LOCUS is the statement in algebraic language of the laws which govern the motion of the point that traces the locus.

When the point moves in the xy-plane, the equation will be in terms of x and y and certain constants. It follows from the definition of a locus that the coördinates of all points on the locus will satisfy its equation and that the coördinates of no other point will satisfy it.

When two points are given, $P_1 \equiv (x_1, y_1)$, $P_2 \equiv (x_2, y_2)$, the distance between them is given by the expression,

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

The Inclination of a line is the angle that the line makes with the x-axis.

The Slope of a line is the tangent of its inclination. If $P_1 \equiv (x_1, y_1)$ and $P_2 \equiv (x_2, y_2)$ are two points in a plane, the slope, m, of a line joining them is

$$m = \frac{y_2 - y_1}{x_2 - x_1} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

If a third point $P_3 \equiv (x_3, y_3)$ divides the line joining the two points $P_1 \equiv (x_1, y_1)$ and $P_2 \equiv (x_2, y_2)$, the segments of the line will be in a certain ratio. Let r equal the ratio $P_1 P_3 : P_3 P_2$. The ratio r will be positive

if P_3 lies between P_1 and P_2, negative if P_3 lies outside the segment $P_1 P_2$. The coördinates of P_3 can be obtained by means of the expressions

$$x_3 = \frac{x_1 + rx_2}{1 + r},\ y_3 = \frac{y_1 + ry_2}{1 + r} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

If P_3 bisects $P_1 P_2$, equations (3) reduce to the forms,

$$x_3 = \frac{x_1 + x_2}{2},\ y_3 = \frac{y_1 + y_2}{2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

The Intercepts of a curve are the distances from the origin to the points where the curve cuts the coördinate axes.

Equations of a Straight Line. All equations of the first degree in x and y represent straight lines, and, conversely, the equations of all straight lines, when reduced to their simplest forms, are of the first degree. When the coördinates of two points on the line, $P_1 \equiv (x_1, y_1)$ and $P_2 \equiv (x_2, y_2)$ are given, the equation of the line thru them is,

$$\frac{y - y_1}{x - x_1} = \frac{y_2 - y_1}{x_2 - x_1} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

Equation (5) is called the TWO-POINT FORM of the equation of a straight line. If the two points lie on the coördinate axes and have the coördinates (a, o) and (o, b), equation (5) reduces to

$$\frac{x}{a} + \frac{y}{b} = 1$$

This is called the INTERCEPT FORM of the equation. If a line has the slope m and passes thru the point $P_1 \equiv (x_1, y_1)$, its equation is

$$y - y_1 = m(x - x_1) \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

If P_1 lies on the y-axis and has the coördinates (o, b) equation (6) becomes

$$y = mx + b \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

Equation (6) is called the SLOPE-POINT form of the equation and equation (7) the SLOPE FORM. It follows from the form of the last equation that in order to determine the slope of a line when its equation is given, it is necessary only to solve the equation for y. Then the coefficient of x is the slope of the line. THE NORMAL FORM of the equation of a straight line. Let p be the length of the perpendicular from the origin upon the line and let a be the angle that this perpendicular makes with the x-axis. Then the equation of a line may be written in the form,

$$x \cos a + y \sin a = p \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

In equation (8), p is always positive and a has any value from 0° to +360°.

REDUCTION TO THE NORMAL FORM. Let the equation of a straight line be $Ax + By + C = 0$, where A, B, C are constants. This equation can be reduced to the normal form by dividing each term by $\pm\sqrt{A^2 + B^2}$. The sign opposite to that of C should be used before the radical. In the resulting equation

$$\frac{A}{\pm\sqrt{A^2 + B^2}}x + \frac{B}{\pm\sqrt{A^2 + B^2}}y + \frac{C}{\pm\sqrt{A^2 + B^2}} = 0$$

$$\cos a = \frac{A}{\pm\sqrt{A^2 + B^2}},\ \sin a = \frac{B}{\pm\sqrt{A^2 + B^2}},\ -p = \frac{C}{\pm\sqrt{A^2 + B^2}}$$

The Distance of a Point $P_1 \equiv (x_1, y_1)$ from the line $Ax + By + C = 0$ is given by the expression

$$d = \frac{Ax_1 + By_1 + C}{\pm\sqrt{A^2 + B^2}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

If the sign of the radical is taken opposite to the sign of C, d will be positive or negative according as P_1 is on the opposite side of the line from the origin or on the same side as the origin.

Slopes of Parallel and of Perpendicular Lines. If two lines are parallel, their slopes are equal. That is $m_1 = m_2$. If two lines are perpendicular to each other the slope of one is the negative reciprocal of the slope of the other. That is, $m_1 = -\dfrac{1}{m_2}$.

Angle Between Two Lines is defined to be the angle formed in turning the second line into the position of the first by counter-clockwise, or positive rotation. If ϕ is the angle between the two lines and m_1 and m_2 their slopes,

$$\tan\phi = \frac{m_1 - m_2}{1 + m_1 m_2} \qquad (10)$$

The Bisectors of the angles between the two lines $Ax + By + C = 0$ and $A_1 x + B_1 y + C_1 = 0$ are given by the expression

$$\frac{A_1 x + B_1 y + C_1}{\pm\sqrt{A_1^2 + B_1^2}} = \pm \frac{Ax + By + C}{\pm\sqrt{A^2 + B^2}} \qquad (11)$$

the signs before the radicals being taken opposite to the signs of C_1.

The Area of a Triangle whose vertices are $P_1 \equiv (x_1, y_1)$, $P_2 \equiv (x_2, y_2)$, $P_3 \equiv (x_3, y_3)$ can be computed from the following formula,

$$\text{Area} = \tfrac{1}{2}\left[x_1(y_2 - y_3) + x_2(y_3 - y_1) + x_3(y_1 - y_2)\right] \qquad (12)$$

This area will be positive if the perimeter of the triangle is traced in the positive direction of rotation, negative if it is traced in the negative direction.

The Circle. If a circle has a radius r and has its center at the point (h, k) it is represented by the equation

$$(x - h)^2 + (y - k)^2 = r^2 \qquad (13)$$

If the center is at the origin, $h = k = 0$ and eq. (13) reduces to

$$x^2 + y^2 = r^2. \qquad (14)$$

The equation $\quad A'x^2 + B'xy + C'y^2 + D'x + E'y + F' = 0. \qquad (15)$

is called the GENERAL EQUATION OF THE SECOND DEGREE in two variables. A comparison of this equation with the expanded form of equation (13) shows that equation (15) is the equation of a circle if $B' = 0$ and $A' = C'$. Making use of this deduction and dividing equation (15) by A' reduces it to the form

$$x^2 + y^2 + Dx + Ey + F = 0 \qquad (16)$$

which is the general equation of a circle, the coördinates of whose center are $h = -\dfrac{D}{2}$, $k = -\dfrac{E}{2}$ and whose radius is $r = \tfrac{1}{2}\sqrt{D^2 + E^2 - 4F}$.

The TANGENT to the circle $x^2 + y^2 = r^2$ has the equation

$$x_1 x + y_1 y = r^2 \qquad (17)$$

where $P_1 \equiv (x_1, y_1)$ is the point of tangency. Similarly, the equation of the tangent to the circle $x^2 + y^2 + Dx + Ey + F = 0$ at the point $P_1 \equiv (x_1, y_1)$ is

$$x_1 x + y_1 y + \frac{D}{2}(x + x_1) + \frac{E}{2}(y + y_1) + F = 0 \qquad (18)$$

If the tangent to the circle $x^2 + y^2 = r^2$ has a given slope m, its equation is

$$y = mx \pm r\sqrt{1 + m^2} \qquad (19)$$

It should be noted that equations (17) and (19) apply only to circles whose centers are at the origin. Equation (18), on the other hand, applies to circles, which have any position with respect to the coördinate axes, when the point of tangency is given.

THE NORMAL to the circle $x^2 + y^2 = r^2$ at the point $P_1 \equiv (x_1, y_1)$ has the equation

$$y_1 x - x_1 y = 0. \qquad (20)$$

When the equation of the circle is $x^2 + y^2 + Dx + Ey + F = 0$, the equation of the normal becomes

$$x_1 y - y_1 x + \frac{D}{2}(y - y_1) - \frac{E}{2}(x - x_1) = 0 \qquad (21)$$

Equation (21) is more general than equation (20), because of the fact that it can be used to write the equation of the normal to a circle which occupies any position whatever with respect to the coördinate axes, whereas equation (20) can be used only when the circle has its center at the origin.

Conic Sections. A conic section, or a conic, is defined to be a curve traced by a point which moves so that its distance from a fixed point always has a constant ratio to its distance from a fixed straight line. Equation (15) always represents a conic section. The fixed point is called the FOCUS of the conic, the fixed straight line is called its DIRECTRIX, and the constant ratio is called its ECCENTRICITY.

Parabola. When the eccentricity e is equal to unity, the curve is called the parabola. The parabola is the conic of most interest to engineers. If the y-axis is taken as the directrix of the curve and the focus is taken on the x-axis with the coördinates $(2p, 0)$, the equation of the parabola is

$$y^2 = 4px - 4p^2 \qquad (22)$$

When the parabola is in this position with respect to the coördinate axes, the x-axis becomes the axis of symmetry of the curve or the AXIS of the curve. The VERTEX of the parabola is the point where it cuts its axis. Here the vertex is half way between the focus and the origin.

If the vertex of the parabola is taken as the origin, equation (22) reduces to the form

$$y^2 = 4px \qquad (23)$$

Equation (23) is the simplest form of the equation of a parabola. The chord of a parabola drawn thru the focus parallel to the directrix is called the LATUS RECTUM of the parabola. In equation (23) the latus rectum is equal to $4p$.

TANGENT AND NORMAL. The tangent to the parabola $y^2 = 4px$ at the point $P_1 \equiv (x_1, y_1)$ has the equation

$$yy_1 = 2p(x + x_1) \qquad (24)$$

If the slope m of the tangent is given, its equation is

$$y = mx + \frac{p}{m}. \qquad (25)$$

The normal to the parabola $y^2 = 4px$ at $P_1 \equiv (x_1, y_1)$ has for its equation

$$y - y_1 = -\frac{y_1}{2p}(x - x_1) \qquad (26)$$

Properties of the Parabola. Let the equation of the parabola be $y^2 = 4px$, then

1. $\overline{MP}^2 = \overline{DD'} \times \overline{OM}$. This relation follows from the equation of the curve and states that, if from any point on the curve a perpendicular is drawn to its axis, the square of this perpendicular is equal to the product of the distance from the vertex to the foot of the perpendicular multiplied by the latus rectum.

2. The subtangent $TM = 2x_1$, that is, $TO = OM$.

3. $\angle FPT = \angle QPH$: Property (3) is made use of in the construction of reflectors. If a source of energy, heat, light, or electricity, is placed at the focus of a parabolic reflector, all rays of energy from the source that strike the surface of the reflector are reflected in lines parallel to the axis of the parabola.

4. $MN = 2p$. That is, the subnormal of a parabola is constant and equal to half the latus rectum.

5. $TF = FP = FN$.

6. TP bisects the angle FPL, and NP bisects the angle FPH. It is seen from property (6) that the tangent and normal drawn to a parabola at any point bisect internally and externally the angles formed by the focal radius drawn to the point of contact and the perpendicular drawn thru that point to the directrix.

Fig. 9.

Construction of a Parabola. A parabola can be constructed by points, as follows, if its equation or the distance from the vertex to the focus is given. Suppose the given equation is $y^2 = 4px$. On the x-axis take $OF = p$ or the given distance. Take $MO = OF$ and draw MD perpendicular to OX. At the right of O take points $a, b, c \ldots$ and at these points draw lines parallel to MD. With a pair of dividers measure the distance Ma. With F as a center and Ma as a radius strike two arcs intersecting aa' in two points P and P'. Similarly with Mb as radius and F as center strike two arcs intersecting bb' in the points Q and Q'. In the same way, as many points as are desired may be found. It follows from the definition of the parabola that the points P and P', Q and Q' . . . are points on the curve. A smooth curve drawn thru these points will be the parabola required.

Fig. 10.

The Ellipse. In the ellipse the eccentricity $e < 1$. If the ellipse has its center at the origin, is symmetrical with respect to both coördinate axes, and has its major axis, equal to $2a$, along the x-axis, its equation is

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (27)$$

In the ellipse represented by equation (27) the minor axis is equal to $2b$.

In the ellipse (27), the distance from the center to the focus is equal to $\sqrt{a^2 - b^2}$. The eccentricity $e = \dfrac{\sqrt{a^2 - b^2}}{a}$. The distances from the foci to a point $P_1 \equiv (x_1, y_1)$ on the curve are equal to $a \pm ex_1$. These distances are called the focal radii of the ellipse to the point P_1. It is evident that the sum of the focal radii to any point P_1 of an ellipse is equal to $2a$, the major axis of the curve. The ellipse having its major axis, equal to $2a$, along the y-axis and its minor axis equal to $2b$, along the x-axis has the equation

$$\frac{x^2}{b^2} + \frac{y^2}{a^2} = 1.$$

If the focal radii be drawn to any point on an ellipse, and tangent and normal be drawn to the ellipse at this point, the tangent and normal bisect, respectively, the exterior and interior angles formed by the focal radii. This property makes it possible to construct the tangent and normal at any point on an ellipse. A tangent to the ellipse $\dfrac{x^2}{a^2} + \dfrac{y^2}{b^2} = 1$ at the point $P_1 \equiv (x_1, y_1)$ has the equation

$$\frac{x_1 x}{a^2} + \frac{y_1 y}{b^2} = 1$$

The Hyperbola. The hyperbola which has its center at the origin, is symmetrical with respect to both axes, and has its transverse axis equal to $2a$, along the x-axis, has for its equation

$$\frac{x^2}{a^2} - \frac{y^2}{b^2} = 1. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (28)$$

In the hyperbola represented by equation (28), b is the real coefficient of the imaginary intercept of the curve on the y-axis, and $2b$ taken along the y-axis is called the conjugate axis.

In hyperbola (28), the distance from the center to the focus is equal to $\sqrt{a^2 + b^2}$ and the eccentricity $e = \frac{\sqrt{a^2 + b^2}}{a}$. The focal radii of hyperbola (28) are equal to $ex_1 \pm a$. Thus, in the case of the hyperbola, the difference of the focal radii drawn to the point P_1 is equal to $2a$, the transverse axis.

6. Probability of Errors

Arithmetic Mean. Observations or measurements of any magnitude differ more or less among themselves. When all known sources of error have been eliminated and all observations made with the same care, one result cannot be accepted as more accurate than the others. In such cases the arithmetical mean of all observations is taken as the most probable value of the magnitude. If x is an observed value, and n, the number of observations; a, the arithmetical mean, is given by the expression,

$$a = \frac{x_1 + x_2 + \ . \ . \ .}{n} = \frac{\Sigma\, x}{n} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Weighted Mean. The circumstances under which the observations are taken may cause some of the results to be more trustworthy than others. For example, suppose that two measurements, x_1 and x_2, of a magnitude are taken, and suppose that x_1, for some reason, is likely to be more accurate than x_2; then x_1 could be given more weight in the mean than x_2 by adding it twice, say. In this case the mean, a, would become

$$a = \frac{2x_1 + x_2}{3}$$

If the different observed values are x_1, x_2, . . . and the weights are p_1, p_2, . . . respectively, the weighted mean, A, has the value,

$$A = \frac{p_1\, x_1 + p_2\, x_2 + \ . \ . \ .}{p_1 + p_2 + \ . \ . \ .} = \frac{\Sigma\, px}{\Sigma\, p}$$

Residuals. If the arithmetical mean is found by equation (1) and each observed value is substracted from the mean, the difference is called the residual. The residuals are taken to be the errors of observation, but they differ from the true errors of observation by as much as the mean differs from the actual value of the magnitude observed. If the residuals are large, it is evident that there is more doubt as to the accuracy of the mean than if the residuals are small. Likewise, if only a few observations are taken, the accuracy of the mean is not so great as it would have been if a long series of observations had been taken. It should be possible, therefore, considering the magnitude of the residuals as well as the number of observations taken, to determine by how great a PROBABLE ERROR the mean

value is likely to be affected. This determination has been made by the METHOD OF LEAST SQUARES, which is based on the mathematical theory of probability. If the probable error is defined to be a quantity such that the error of the mean is more likely to be smaller than this quantity rather than greater, then the probable error of the mean of n observations is given by the expression

$$E = 0.6745 \sqrt{\frac{\Sigma v^2}{n(n-1)}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where Σv^2 is the sum of the squares of the residuals. The probable error of any one of the n observations is

$$E_0 = 0.6745 \sqrt{\frac{\Sigma v^2}{n-1}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

From equations (2) and (3) it can be seen that the probable error of the mean is less than that of any observation in the ratio $1 : \sqrt{n}$.

Probable Error of Weighted Mean. If $p_1, p_2 \ldots$ are the weights to be attached to the observed values $x_1, x_2, \ldots$, then the probable error of the weighted mean is

$$E = 0.6745 \sqrt{\frac{\Sigma pv^2}{(n-1)\Sigma p}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

where v is one of the residuals. The probable error of an observation whose weight is unity is

$$E_0 = 0.6745 \sqrt{\frac{\Sigma pv^2}{n-1}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

If $p_1 = p_2 = \ldots = 1$, it is evident that equations (4) and (5) reduce respectively to equations (2) and (3).

Example 1. The following series of observations was taken in which all the results were considered of equal weight.

Observed values	v	v^2
3.68	− 0.43	0.1849
3.11	− 1.00	1.0000
4.76	+ 0.65	0.4225
2.75	− 1.36	1.8496
4.15	+ 0.04	0.0016
5.08	+ 0.97	0.9409
2.95	− 1.16	1.3456
6.35	+ 2.24	5.0176
3.78	− 0.33	0.1089
4.49	+ 0.38	0.1444
10|41.10		$\Sigma v^2 = 11.0160$
$a = 4.11$		

$$\frac{\Sigma v^2}{n-1} = \frac{11.0160}{9} = 1.224 \,. \quad \sqrt{\frac{\Sigma v^2}{n-1}} = 1.106.$$

$\therefore E_0 = 0.6745 \times 1.106 = 0.746$, probable error of one observation.

$\therefore E = \dfrac{0.746}{\sqrt{10}} = 0.236$, probable error of mean.

Example 2. Suppose the observations in Example 1 have the weights assigned in the following table:

p	Observed value	v	v^2	pv^2
2	3.68	−0.43	0.1849	0.3698
1	3.11	−1.00	1.0000	1.0000
1	4.76	+0.65	0.4225	0.4225
1	2.75	−1.36	1.8496	1.8496
3	4.15	+0.04	0.0016	0.0048
1	5.08	+0.97	0.9409	0.9409
1	2.95	−1.16	1.3456	1.3456
1	6.35	+2.24	5.0176	5.0176
3	3.78	−0.33	0.1089	0.3267
2	4.49	+0.38	0.1444	0.2888
$\Sigma p = 16$	10 | 41.10 4.11 = a			$\Sigma pv^2 = 11.5663$

$$\sqrt{\frac{\Sigma pv^2}{n-1}} = \sqrt{\frac{11.5663}{9}} = 1.134$$

$\therefore\ E_0 = 0.6745 \times 1.134 = 0.7649$, probable error of an observation whose weight is unity.

$\therefore\ E = \dfrac{E_0}{\sqrt{\Sigma p}} = \dfrac{0.7649}{4} = 0.1912$, probable error of the weighted mean.

7. Applications of Calculus

Explicit and Implicit Functions. In differential calculus one variable is an explicit function of another when the function is solved for the first variable in terms of the second. In the expression $y = x^3 - x + 1$, y is an explicit function of x. One variable is an implicit function of another when the function is solved for neither variable. For example, in the equation $x^2 + y^2 = 25$, y is an implicit function of x. In this expression, x is also an implicit function of y. The elementary rules for differentiating explicit functions are assumed to be known. A second derivative is obtained by differentiating a first derivative, a third, by differentiating a second, and so on.

Differentiating Implicit Functions. Suppose there is given $f(x, y) = 0$. Sometimes in such a function, when it is desired to obtain $\dfrac{dy}{dx}$ it is difficult or impossible to solve the expression for either variable. Then it is important to be able to differentiate an implicit function. The method of procedure used in finding a first and second derivative of an implicit function will be shown by a simple example.

Given the function $b^2x^2 + a^2y^2 = a^2b^2$. Differentiating term by term gives $2b^2x + 2a^2y\dfrac{dy}{dx} = 0$. Hence, $\dfrac{dy}{dx} = -\dfrac{b^2x}{a^2y}$ (1). Differentiating once more, $\dfrac{d^2y}{dx^2} = -\dfrac{a^2y \cdot b^2 - b^2x \cdot a^2\dfrac{dy}{dx}}{a^4y^2}$, substitute value of $\dfrac{dy}{dx}$ from (1). Then $\dfrac{d^2y}{dx^2} =$

$$-\frac{b^2y - b^2x\left(-\dfrac{b^2x}{a^2y}\right)}{a^2y^2} = -\frac{a^2b^2y^2 + b^4x^2}{a^4y^3} = -\frac{b^2(b^2x^2 + a^2y^2)}{a^4y^3} = -\frac{a^2b^4}{a^4y^3} = -\frac{b^4}{a^2y^3}$$ since from the function $b^2x^2 + a^2y^2 = a^2b^2$.

Geometric Interpretation of Derivative. The derivative $\frac{dy}{dx}$ represents the slope of the tangent at a point P on the curve $y = f(x)$. Let $\frac{dy}{dx}$ be the value of $\frac{dy}{dx}$ at $P_1 \equiv (x_1, y_1)$. For example, in $x^2 + y^2 = 25$, $\frac{dy}{dx} = -\frac{x}{y}$. Let $P_1 \equiv (3, -4)$. Then $\frac{dy_1}{dx_1} = \left[-\frac{x}{y}\right]_{\substack{x=3\\y=-4}} = -\frac{3}{-4} = \frac{3}{4}$. Since $m = \frac{dy_1}{dx_1}$ = slope of tangent at P_1, the slope of the normal $= -\frac{1}{m} = -\frac{dx_1}{dy_1}$.

The equation of the TANGENT at P_1 is then $y - y_1 = \frac{dy_1}{dx_1}(x - x_1)$. The equation of the NORMAL at the same point is $y - y_1 = -\frac{dx_1}{dy_1}(x - x_1)$. Length of SUBNORMAL at $P_1 = y_1 \frac{dy_1}{dx_1}$. Length of SUBTANGENT at $P_1 = y_1 \frac{dx_1}{dy_1}$. Length of TANGENT at $P_1 = y_1 \sqrt{1 + \left(\frac{dx_1}{dy_1}\right)^2}$. Length of NORMAL at $P_1 = y_1 \sqrt{1 + \left(\frac{dy_1}{dx_1}\right)^2}$.

Parametric Equations. Sometimes a curve is represented by two equations $y = f(t)$, $x = \phi(t)$ (2) instead of by one equation $y = f(x)$ (3). This is especially true in problems of motion. Equations (2) are called PARAMETRIC EQUATIONS and t is called the PARAMETER. See (6), (20), (28a) and (39).

Maxima and Minima. In many practical problems it is necessary to deal with functions that have a maximum or minimum value, and it becomes desirable to find the value of the variable that produces such a maximum or minimum value in the function. The conditions that must be satisfied in order that a function $y = f(x)$ may have a maximum or minimum value are, first, that $\frac{dy}{dx} = 0$ or ∞, and second, that $\frac{dy}{dx}$ change sign at the maximum or minimum point. At a maximum point, $\frac{dy}{dx}$ changes sign from + to − as the point moves along the curve from left to right. At a minimum, $\frac{dy}{dx}$ changes sign from − to +. Hence, for the case where $\frac{dy}{dx} = 0$, in order to obtain the values of the variable for which the function has a maximum or minimum value, the first derivative of the function is placed equal to zero and the resulting equation is solved. The values of the variable obtained from this solution are called its critical values. The next step is to test the first derivative, using one critical value at a time, first with a value of the variable a little less than the critical value, then with a value a little greater than the critical value. If the first derivative changes sign from + to −, the function has a maximum for that value of the variable. If it changes sign from − to +, the function has a minimum for that value of the variable. If the derivative does not change sign, the function has neither a maximum nor a minimum at the point considered.

Example. Given, $y = (x - 2)^2 (x + 1)$, solve for maximum and minimum values.

$$\frac{dy}{dx} = (x - 2)^2 + 2(x + 1)(x - 2) = 3x(x - 2).$$

To find critical values, place $3x(x - 2) = 0$. This gives $x = 0$ or 2, which are the critical values. Test first derivative for each critical value,

$$x = 0 \left\{ \begin{array}{l} x < 0, \dfrac{dy}{dx} \text{ is } + \\ x > 0, \dfrac{dy}{dx} \text{ is } - \end{array} \right\} \begin{array}{l} \therefore x = 0, \\ \text{the max.} \end{array} \qquad x = 2 \left\{ \begin{array}{l} 0 < x < 2, \dfrac{dy}{dx} \text{ is } - \\ x > 2\,\dfrac{dy}{dx} \text{ is } + \end{array} \right\} \begin{array}{l} \therefore x = 2, \\ \text{the min.} \end{array}$$

By substituting $x = 0$ and $x = 2$ in the function it is found that $y = 4$, $y = 0$ are the values of the function at the maximum and minimum points respectively. For a treatment of the case where $\frac{dy}{dx} = \infty$ at a maximum or minimum point, see (6), (20), (28a) and (39).

Given $y = f(x)$, to obtain dy it is simply necessary to find $\frac{dy}{dx}$ and to multiply this expression by dx.

Points of Inflection. A point of inflection separates an arc of a curve that is concave upward from an arc that is concave downward. At a point of inflection of $y = f(x)$, $\frac{d^2y}{dx^2} = 0$ and changes sign at that point. See (6), (20), (28a) and (39).

Rates. Let $y = f(x)$ be considered as a curve generated by a moving point. Then x and y can be regarded as functions of the time. The method of solution employed in problems involving rates can best be illustrated by examples.

Example 1. In the function $y = 2x^3 + 6$, what is the value of x at the point where y increases 54 times as fast as x? $y = 2x^3 + 6$, $\frac{dy}{dt} = \frac{dy}{dx}\frac{dx}{dt} = 6x^2\frac{dx}{dt}$; but, it is given that $\frac{dy}{dt} = 54\frac{dx}{dt}$; hence $54\frac{dx}{dt} = 6x^2\frac{dx}{dt}$ or $9 = x^2$ and $x = \pm 3$.

Example 2. A circular plate of metal expands by heat so that its radius increases uniformly at the rate of 0.01 in per sec. At what rate is the surface increasing when the radius is 2 in? Let x = radius, y = area; then $y = \pi x^2$ and $\frac{dy}{dt} = 2\pi x\frac{dx}{dt}$; but $\frac{dx}{dt} = 0.01$ in when $x = 2$; substituting above, gives $\frac{dy}{dt} = 2\pi \times 2 \times 0.01 = 0.04\pi$ sq in per sec.

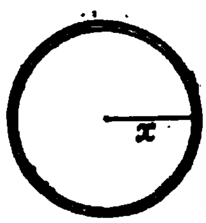

Fig. 11.

Curvature and Radius of Curvature. The rate of change of direction of the tangent to a curve as the point of tangency describes the curve is called curvature, and is denoted by K. In the circle $K = \frac{1}{R}$. That is, the curvature of a circle is constant and equal to the reciprocal of the radius. Since the radius of curvature of a curve at a given point is defined to be the radius of the circle having the same curvature as the curve at that point, the value of the radius of curvature R of any curve in rectangular coördinates at any point is given by the expression

$$R = \frac{1}{K} = \frac{\left[1 + \left(\dfrac{dy}{dx}\right)^2\right]^{3/2}}{\dfrac{d^2y}{dx^2}}$$

Taylor's and Maclaurin's Formulas. If $f(a)$ equals the value of $f(x)$ when a is substituted for x, and $\lfloor\underline{n} = 1.2.3 \ldots n$, then

$$f(x) = f(a) + \frac{x-a}{\lfloor\underline{1}} f'(a) + \frac{(x-a)^2}{\lfloor\underline{2}} f''(a) + \frac{(x-a)^3}{\lfloor\underline{3}} f'''(a) + \ldots \quad (2)$$

is the form of Taylor's formula that is used to expand a function of one variable, say x, into a series in the powers of $x - a$.

Example. **Expand** $f(x) = 3x^2 - 2x + 1$ **in powers of** $x - 1$:

$$\begin{aligned} f(x) &= 3x^2 - 2x + 1 & f(1) &= 2 \\ f'(x) &= 6x - 2 & f'(1) &= 4 \\ f''(x) &= 6 & f''(1) &= 6 \\ f'''(x) &= 0 & f'''(1) &= 0. \end{aligned}$$

Substituting in (2) gives,

$$f(x) = 2 + 4(x-1) + \frac{6}{\lfloor\underline{2}}(x-1)^2 = 2 + 4(x-1) + 3(x-1)^2 \text{ Ans.}$$

If $a + x$ is substituted for x in (2), the series takes the form,

$$f(a+x) = f(a) + \frac{x}{\lfloor\underline{1}} f'(a) + \frac{x^2}{\lfloor\underline{2}} f''(a) + \frac{x^3}{\lfloor\underline{3}} f'''(a) + \ldots \quad (3)$$

Series (3) is used to expand a function of the sum of two quantities into a series proceeding according to the powers of one of the quantities.

In (3), if zero is substituted for a, the special form of Taylor's formula is obtained which is called Maclaurin's formula. This formula is

$$f(x) = f(0) + \frac{x}{\lfloor\underline{1}} f'(0) + \frac{x^2}{\lfloor\underline{2}} f''(0) + \frac{x^3}{\lfloor\underline{3}} f'''(0) + \ldots \quad (4)$$

Series (4) is used to expand a function of one variable into a series, proceeding according to the powers of that variable.

Integration of Algebraic Functions. The integration formula, which is one of the simplest and at the same time one of those most used by engineers, is the following

$$\int v^n\,dv = \frac{v^{n+1}}{n+1} + C \quad \ldots \quad (5)$$

In equation (5) C is the constant of integration. This formula is valid for all values of n except $n = -1$. If $n = -1$, $v^n\,dv$ becomes $\frac{dv}{v}$ and the formula becomes $\int \frac{dv}{v} = \log v + C$

Example 1. $\int x^3\,dx$. Here $v = x$, $n = 3$, $\therefore \int x^3\,dx = \frac{1}{4}x^4 + C$.

Example 2. $\int x^{\frac{3}{4}}\,dx$. Here $v = x$, $n = \frac{3}{4}$, $\therefore \int x^{\frac{3}{4}}\,dx = \frac{x^{\frac{7}{4}}}{7/4} + C = \frac{4}{7}x^{\frac{7}{4}} + C$.

Example 3 $\int (3x^2 - 4x + 1)^{-2}(3x - 2)\,dx$. In this case v is a polynomial $3x^2 - 4x + 1$. $n = -2$, and $dv = 6x - 4$. To make $(3x - 2)dx = dv$ it is necessary to multiply by 2. Since the value of the expression to be integrated must not be changed, if it is multiplied by 2 it must also be divided by 2. Hence the integral becomes $\frac{1}{2}\int (3x^2 - 4x + 1)^{-2}(6x - 4)\,dx$ which on integration is equal to

$$\frac{1}{2}\,\frac{(3x^2 - 4x + 1)^{-1}}{-1} + C = -\frac{1}{2(3x^2 - 4x + 1)} + C.$$

Example 4. $\int \frac{x^5 - 4x^3 - 6x + 1}{x^2} dx$ on dividing the numerator by the denominator becomes

$\int \left(x^3 - 4x - \frac{6}{x} + x^{-2}\right) dx$ which equals on integration $\frac{1}{4}x^4 - \frac{4x^2}{2} - 6 \log x + \frac{x^{-1}}{-1} + C = \frac{1}{4}x^4 - 2x^2 - 6\log x - x^{-1} + C.$

For the integrals of other algebraic functions, a table of integrals (41) should be consulted.

Integration of Trigonometric Functions. In finding areas where certain substitutions are used, the following types of integrals result, $\int \sin^2 x\, dx$ or $\int \cos^2 x\, dx$. Integration of these expressions can be performed by the use of the substitutions $\sin^2 x = \frac{1}{2}(1 - \cos 2x)$, $\cos^2 x = \frac{1}{2}(1 + \cos 2x)$. It should be remembered in finding the integrals of trigonometric functions by means of formulas, involving the angle v, that dv is the differential of the angle, whatever the angle is.

Example. Given $\int \cos v\, dv = \sin v + C$. Find $\int \cos 2x\, dx$. Here $v = 2x$, hence $dv = 2dx$, $\therefore \int \cos 2x\, dx = \frac{1}{2}\int \cos 2x \cdot 2dx = \frac{1}{2}\sin 2x + C.$

For other trigonometric forms, the use of a table of integrals (41) is advised.

Constant of Integration. Since $d(x^2) = 2x$, $\int 2x\, dx = x^2$; $d(x^2 - 3) = 2x$, $\int 2x\, dx = x^2 - 3$; $d(x^2 + C) = 2x$, $\int 2x\, dx = x^2 + C$. The differentiation of the result of any integration must give the expression at the right of the integral sign. Since the derivative of any constant is equal to zero, the existence of a constant in the result of every integration must be assumed. This constant is called the constant of integration. In any practical problem, the value of the constant of integration must be determined before the results of integration may be used. When the integration is performed between limits, the constant disappears thru the operation of subtraction.

Example 1. Find the area between the curve $y = x^3$, the x-axis, and the two ordinates $x = 2$ and $x = 3$. $A = \int y dx$. Here $A = \int_2^3 y dx$ and $y = x^3$. Hence $A = \int_2^3 x^3 dx = \left[\frac{1}{4}x^4 + C\right]_2^3$. To find the value of the expression in the bracket substitute in it successively $x = 3$ and $x = 2$ and subtract the latter result from the former. This operation gives, $A = \left[\frac{1}{4} \cdot 81 + C\right] - \left[\frac{1}{4} \cdot 16 + C\right] = \frac{81}{4} - \frac{16}{4} = \frac{65}{4}.$

Example 2. Another method of eliminating the constant is to determine its value by making use of initial conditions given in the problem. Suppose a body is moving in space acted upon by a constant acceleration equal to g. Also suppose that when the time $t = 0$, the distance passed over $s = a$, and the velocity $v = b$. Find the relation between s and t.

Acceleration $= \frac{dv}{dt} = g$. Integrating, $v = gt + c_1$. But $v = b$ when $t = 0$. Hence, $b = 0 + c_1$, that is, $c_1 = b$. $\therefore v = \frac{ds}{dt} = gt + b$ and integrating again, $s = \frac{1}{2}gt^2 +$

$bt + c_2$. But $s = a$ when $t = 0$. Hence, $a = 0 + 0 + c_2$ or $c_2 = a$. $\therefore s = \frac{1}{2}gt^2 + bt + a$, the relation required.

Areas. In rectangular coördinates the area between a curve, two ordinates $x = a$ and $x = b$, and the x-axis is expressed by the definite integral $A = \int_a^b ydx$. In order to find the value of this integral, it is necessary to substitute for y its equivalent in x obtained from the equation of the curve. An example illustrating this process has been given in the discussion of the constant of integration.

MECHANICS

Mechanics is the science which treats of the fundamental relations between force, mass, space and time. The three important systems of units which are used in the measurement of these quantities may be tabulated as follows:

	Force	Mass	Space	Time
English, engineer's	pound	gee-pound	foot	second
English, absolute	poundal	pound	foot	second
French, metric	dyne	gramme	centimeter	second

8. Force

Definitions. An action, in the nature of a push or a pull, exerted by one material body upon another, is called a FORCE and a similar action between parts, or particles, of the same body is called a STRESS. These actions are actually distributed over an area, but a force is usually treated as tho it were concentrated at a point, called the point of application, and acted in a line, called the LINE OF ACTION. A force is completely specified when its magnitude, action line and direction are given, and it may be graphically represented by a directed line, called the FORCE VECTOR, whose length, to some chosen scale, represents the magnitude of the force. Any point in the action line may be assumed to be the point of application without any change in the effect produced by the force. The force of attraction between any material body and the earth is called the WEIGHT of the body, while the weight per unit volume is called the HEAVINESS. The weight of a pound mass is taken as the unit of force in the English engineer's system of units and is called the pound's weight or, more commonly, simply a pound, but it is necessary in equational relations to distinguish carefully between the pound mass and the pound's weight.

The Moment of a Force, with respect to a point, is a name given to the product of the magnitude of the force and the perpendicular distance from the point to the action line of the force. The name COUPLE is given to two equal, parallel forces, oppositely directed, and the product of either force and the perpendicular distance between their action lines is called the MOMENT of the couple, since it represents the aggregate moment of the two forces with respect to any point in their plane. A couple may be moved anywhere in its own plane, or into any parallel plane, without changing its effect, and it may be graphically represented by a directed line, perpendicular to the plane of the couple, which points in the direction from which the couple must be viewed to appear positive, and whose length represents

the magnitude of the couple moment. A counter-clockwise moment is usually considered positive and a clockwise moment negative, except in the discussion of bending moments where the opposite convention is advantageous.

Force Systems. A number of forces acting simultaneously on a body constitute a FORCE SYSTEM, and the single force, or couple, which would produce the same effect is called the RESULTANT of the system. If the forces of a system have a common action line, the system is said to be COLLINEAR and if the action lines intersect in a common point, the system is said to be CONCURRENT; otherwise it is a PARALLEL or a NONCONCURRENT system. If the action lines are confined to the same plane, the system is called a PLANE or COPLANAR system; if not, it is called a SPACE system. It is a physical axiom, that the resultant of two concurrent forces is the single force which may be represented, in magnitude and direction, by the diagonal of the parallelogram whose adjacent sides represent the given forces, and it is easily proved that the moment of this resultant, with respect to any point in the plane of the forces, is equal to the algebraic sum of the moments of the given forces with respect to the same point. Stated in algebraic form, the graphic relations, shown in Fig. 12, are; $R = \sqrt{P_1^2 + P_2^2 + 2\ P_1\ P_2 \cos\theta}$, $\sin\alpha = P_1 \sin\theta\ /\ R$, $Rr = P_1 p_1 + P_2 p_2$. For the special case of $\theta = 90°$, Fig. 13, $P_x = R\cos\alpha$ and $P_y = R\sin\alpha$, where P_x and P_y are the so called RECTANGULAR COMPONENTS of R.

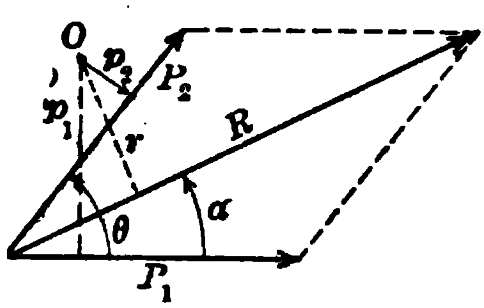

Fig. 12

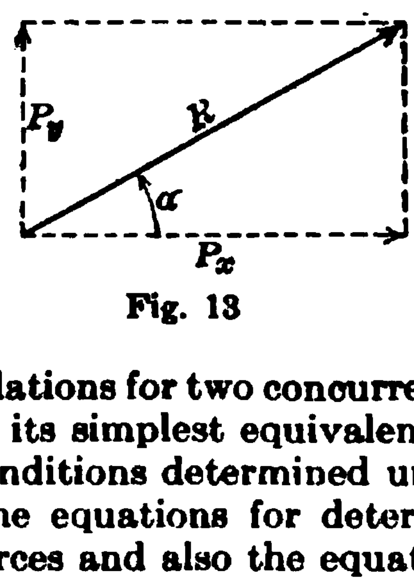

Fig. 13

If a force is replaced by its two rectangular components, one of which is parallel to a given axis and the other in a plane perpendicular to it, the product of the perpendicular component, and the perpendicular distance between its action line and the axis, is called the MOMENT of the given force with respect to that axis. By the application and extension of these fundamental relations for two concurrent forces, any given system of forces may be reduced to its simplest equivalent, in general to a single force and a couple, and the conditions determined under which these resultants may have a zero value. The equations for determining the resultants of the different systems of forces and also the equations of equilibrium, may be listed as follows:

Table I.—Equations for Determining Resultant. Equilibrium Equations

	Plane System	Space System	Plane	Space
Collinear.....	$R = \Sigma P$		$\Sigma P = 0$	
Parallel......	$R = \Sigma P$ $r = \Sigma(Py)/R$	$R = \Sigma P$ $x_0 = \Sigma(Px)/R$ $y_0 = \Sigma(Py)/R$	$\Sigma P = 0$ $\Sigma(Py) = 0$	$\Sigma P = 0$ $\Sigma(Px) = 0$ $\Sigma(Py) = 0$
Concurrent...	$R = \sqrt{\Sigma P_x^2 + \Sigma P_y^2}$ $\tan\alpha_0 = \Sigma P_y / \Sigma P_x$	$R = \sqrt{\Sigma P_x^2 + \Sigma P_y^2 + \Sigma P_z^2}$ $\cos\alpha_0 = \Sigma P_x / R$ $\cos\beta_0 = \Sigma P_y / R$ $\cos\gamma_0 = \Sigma P_z / R$	$\Sigma P_x = 0$ $\Sigma P_y = 0$	$\Sigma P_x = 0$ $\Sigma P_y = 0$ $\Sigma P_z = 0$

Table I.—Equations for Determining Resultant. Equilibrium Equations *(Continued)*

	Plane System	Space System	Plane	Space
Nonconcurrent	$R=\sqrt{\Sigma P_x^2+\Sigma P_y^2}$ $\tan\alpha_0=\Sigma P_y/\Sigma P_x$ $r=\Sigma(P_y x-P_x y)/R$ $y_0=\Sigma(P_x y)/\Sigma P_x$ $x_0=\Sigma(P_y x)/\Sigma P_y$	$R=\sqrt{\Sigma P_x^2+\Sigma P_y^2+\Sigma P_z^2}$ $\cos\alpha_0=\Sigma P_x/R$ $\cos\beta_0=\Sigma P_y/R$ $\cos\gamma_0=\Sigma P_z/R$ $M_x=\Sigma(P_y z-P_z y)$ $M_y=\Sigma(P_z x-P_x z)$ $M_z=\Sigma(P_x y-P_y x)$ $M=\sqrt{M_x^2+M_y^2+M_z^2}$ $\cos\alpha_c=M_x/M$ $\cos\beta_c=M_y/M$ $\cos\gamma_c=M_z/M$	$\Sigma P_x=0$ $\Sigma P_y=0$ $M_z=0$ or $M_A=0$ $M_B=0$ $M_C=0$	$\Sigma P_x=0$ $\Sigma P_y=0$ $\Sigma P_z=0$ $M_x=0$ $M_y=0$ $M_z=0$

Explanation of Notation. With reference to any chosen set of axes, α, β and γ are the angles between the action line of any force, P, and the X, Y and Z axes respectively, while x, y and z are the coördinates of any point on the action line, the assumed point of application. These same letters, with a zero subscript, refer similarly to the resultant, R, and the perpendicular distance from the origin to the action line of the resultant is represented by r. $P_x = P\cos\alpha$, $P_y = P\cos\beta$ and $P_z = p\cos\gamma$ are the rectangular components parallel to the respective axes, while M_x, M_y and M_z, the aggregate moments of the force system with respect to the X, Y and Z axes, are equivalent to three couples whose planes of action are perpendicular to the respective axes. These three couples may be replaced by a single couple, M, whose plane of action is perpendicular to a line which makes the angles α_c, β_c and γ_c with the X, Y and Z axes. Any plane system is assumed to act in the $X\,Y$ plane, and since α and β are then complementary angles, the $\cos\beta$ may be replaced by $\sin\alpha$. In a plane parallel system the X axis, and in a space parallel system the Z axis, is assumed to have the same direction as the forces.

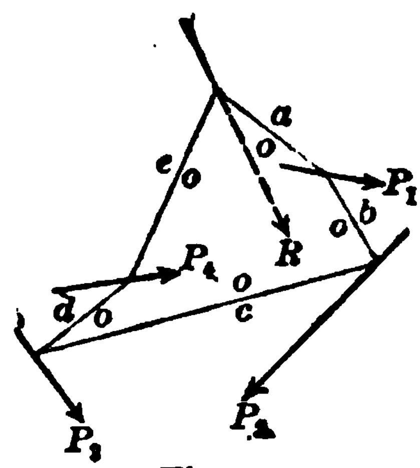

Fig. 14

Graphic Methods. In Fig. 14, let P_1, P_2, P_3, P_4, represent the forces of any given plane system. Draw the force polygon (see Fig. 15), $ABCDE$ with sides respectively parallel and proportional to the given forces. The closing side EA, reversed in direction, represents the magnitude and direction of the resultant of the given system. To locate its action line, take any convenient pole, as O, and connect it with the points A, B, C, D, E by the rays OA, OB, OC, OD and OE. Then, in Fig. 14, draw the strings oa, ob, oc, od, oe, parallel to the corresponding rays, making consecutive strings intersect in the action line of the force to whose vector extremities the corresponding rays were drawn. The intersection of the

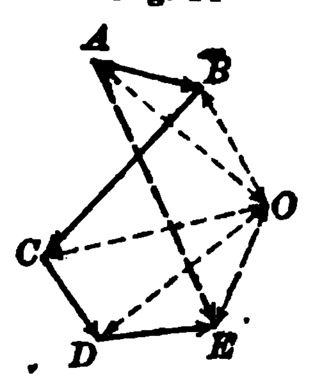

Fig. 15

strings *oa* and *oe* determines a point in the action line of the resultant force, which may now be drawn thru this point, parallel to the direction previously determined. If the force polygon closes, that is if the points A and E coincide, the system is a balanced system, unless the strings *oa* and *oe* are parallel instead of coincident, in which case the resultant of the given system is a couple, with a force represented by the ray OA and an arm equal to the perpendicular distance between the strings *oa* and *oe*. If a system of forces in space is projected on each of the three coördinate planes, the resultants of the three plane systems so formed are the projections of the resultant of the space system. It should be seen that the rays drawn to the extremities of any force vector represent possible component forces by which that force may be replaced, and that the corresponding strings in the STRING POLYGON are the chosen action lines of these components.

Friction is a name given to the component force, tangent to the surfaces of contact of two bodies, which tends to oppose or prevent their relative sliding motion. This force may have any value between zero and a maximum value, called the LIMITING FRICTION which exists when slipping takes place, or is impending. The fundamental law of friction is, that for any given pair of surfaces, the ratio of the limiting friction to the normal pressure between the surfaces is a constant, called the COEFFICIENT OF FRICTION for those surfaces; STATIC, if slipping is impending; KINETIC, if slipping is actually taking place. Stated in symbols, $F = fN$. The coefficient of static friction is, in general, slightly larger than the kinetic coefficient for the same surfaces. The ANGLE OF FRICTION is defined as the limiting angle which the resultant reaction makes with the normal to the contact surfaces, and the ANGLE OF REPOSE is defined as the angle which the contact surfaces make with the horizontal, when sliding is impending under the action of gravity alone. The transmission of power by means of rope drives or belts is possible because of the friction force between them and the pulley surface. The difference between the driving and the following tension is equal to the total friction, and the relation between these tensions is given by $P_1 = P_2 e^{fa}$, where P_1 is the driving and P_2 the following tension, f is the coefficient of friction, a is the arc of contact, in radians, and e is the Naperian base.

Rolling Resistance. When a body, of circular cross-section, rolls over any surface, the resultant reaction of the surface acts at a point whose perpendicular distance, ahead of the radius normal to the surface, is called the COEFFICIENT OF ROLLING RESISTANCE and is represented by c in Fig. 16. It should be carefully noted that this coefficient is a distance, not a ratio, and is usually expressed in inches. Since the resultant reaction is not normal to the surface, it has a backward component, called the ROLLING RESISTANCE which opposes the motion of the body. The force, P, necessary to overcome this resistance is given by $P = (c/r)W$, if it is applied at the center, and by $P = (c/d)W$ if it is applied at the top. When a roller acts between two surfaces, so that there is a rolling resistance both above and below the roller, the force which must be applied at the upper surface, to maintain a uniform motion, is given by $P = (c_1+c_2)W/d$, where c_1 and c_2 are the respective coefficients of rolling resistance for the two surfaces.

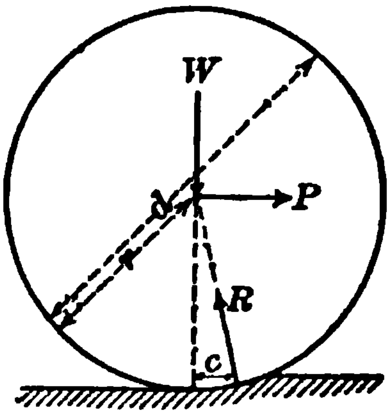

Fig. 16

9. Gravity and Inertia Integrals

Center of Gravity. The attraction of the earth for the different particles of a material body forms a system of forces in space which closely approximates to a parallel system, and the point thru which the resultant of this system always passes, no matter how the body may be turned, is called the center of gravity. If the body is homogeneous this point coincides with the CENTROID, which may be defined as the point whose coördinates are the means of the corresponding coördinates of all the points of a volume, area or line. The coördinates of this point may be determined by means of the formulas, already listed, for locating the resultant of any system of parallel forces in space. If W, V, A and L represent respectively weight, volume, area and line,

$$W\bar{x} = \int x\,dW \qquad W\bar{y} = \int y\,dW \qquad W\bar{z} = \int z\,dW$$

$$V\bar{x} = \int x\,dV \qquad V\bar{y} = \int y\,dV \qquad V\bar{z} = \int z\,dV$$

$$A\bar{x} = \int x\,dA \qquad A\bar{y} = \int y\,dA \qquad A\bar{z} = \int z\,dA$$

$$L\bar{x} = \int x\,dL \qquad L\bar{y} = \int y\,dL \qquad L\bar{z} = \int z\,dL$$

the different forms being derived by the successive cancellation of a constant heaviness, a constant small thickness and a constant small width. The point so located is strictly the center of gravity of the body or the centroid of the volume, area or line, altho these terms are frequently used interchangeably.

Finite Parts. If a body can be imagined to be divided into a number of finite parts, such that the location of the center of gravity of each part is known, then the center of gravity of the body is located by

$$\bar{x} = \frac{\Sigma x\,W}{\Sigma W} = \frac{\Sigma x\,V}{\Sigma V} = \frac{\Sigma x\,A}{\Sigma A} = \frac{\Sigma x\,L}{\Sigma L}$$

with similar expressions for y and z, where W, V, A and L represent respectively the weight, volume, area or length of the finite part, and x, y and z are distances of the center of gravity of the part from the chosen axes or planes of reference.

Moment of Inertia is a name given to certain type integrals of the form $\int r^2 dm$, or $\int r^2 dA$, called respectively the mass moment of inertia and the area moment of inertia, where r is the perpendicular distance from any differential mass, or area, to the axis with respect to which the moment of inertia is reckoned. A summation product of this type appears in any discussion of the flexural strength, or the rotary motion, of any material body, and its value must be known in order to complete the discussion. The symbol I, or J, is used to represent this integral, and the name RADIUS OF GYRATION is given to the square root of the ratio I/m, or I/A. The radius of gyration, k, represents the distance from the axis to the point where the mass, or area, might be conceived to be concentrated without changing the value of the moment of inertia. The number of units of mass in a body is determined, in the English engineer's system of units, by dividing the weight in pounds by 32.2, the approximate value of the gravitational acceleration, in feet per second. DENSITY is defined as the amount

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Area | **Mass**

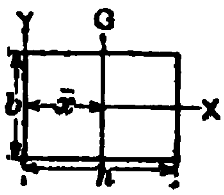

Fig. 17

$A = bh$
$\bar{x} = \frac{1}{2}h$
$\bar{I} = bh^3/12 = Ah^2/12$
$I_x = hb^3/12 = Ab^2/12$
$I_y = bh^3/3 = Ah^2/3$

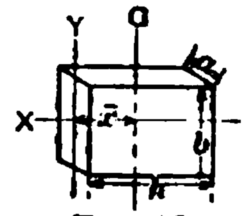

Fig. 18

$V = abh$
$\bar{x} = \frac{1}{2}h$
$I = m(h^2+a^2)/12$
$I_x = m(a^2+b^2)/12$
$I_y = m(4h^2+a^2)/12$

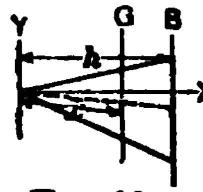

Fig. 19

$A = \frac{1}{2}bh$
$\bar{x} = 2h/3$
$\bar{I} = bh^3/36 = Ah^2/18$
$I_B = bh^3/12 = Ah^2/6$
$I_y = bh^3/4 = Ah^2/2$

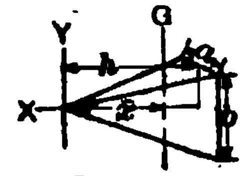

Fig. 20

$V = abh/3$
$\bar{x} = 3h/4$
$\bar{I} = m(3h^2+4a^2)/80$
$I_x = m(a^2+b^2)/20$
$I_y = m(12h+a)/20$

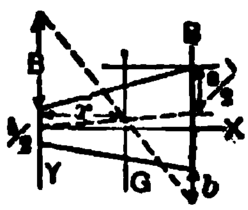

Fig. 21

$A = \frac{1}{2}h(B+b)$
$\bar{x} = h(2B+b)\ (B+b)/3$
$\bar{I} = h^3 \dfrac{(B^2+4Bb+b^2)}{36(B+b)}$
$I_B = h^3(B+3b)/12$
$I_y = h^3(3B+b)/12$

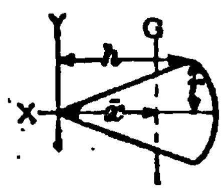

Fig. 22

$V = \pi hr^2/3$
$\bar{x} = 3h/4$
$\bar{I} = 3m(h^2+4r^2)/80$
$I_x = 3mr^2/10$
$I_y = 3m(4h^2+r^2)/20$

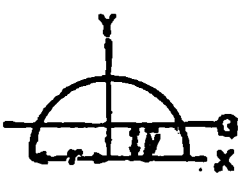

Fig. 23

$A = \frac{1}{2}\pi r^2$
$\bar{y} = 4r/3\pi$
$\bar{I} = 0.11\ r^4$
$I_x = I_y = \pi r^4/8 = Ar^2/4$
$I_z = \pi r^4/4 = Ar^2/2$

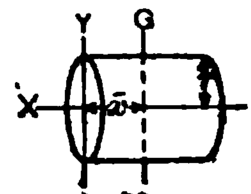

Fig. 24

$V = \pi r^2 h$
$\bar{x} = \frac{1}{2}h$
$\bar{I} = m(h^2+3r^2)/12$
$I_x = \frac{1}{2}mr^2$
$I_y = m(4h^2+3r^2)/12$

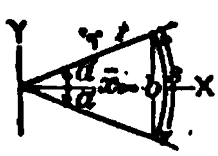

Fig. 25

$A = ar^2 = 2a^\circ\ \pi r^2/360$
$\bar{x} = 2rb/3s = \frac{2}{3}\ r\ \dfrac{\sin a^\circ}{a}$
$I_x = \frac{1}{4}Ar^2(1 - \sin a^\circ \cos a^\circ/a)$
$I_y = \frac{1}{4}Ar^2(1 + \sin a^\circ \cos a^\circ/a)$
$I_z = \frac{1}{2}Ar^2$

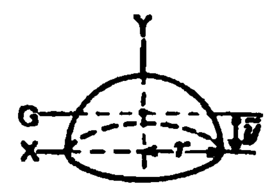

Fig. 26

$V = 2\pi r^3/3$
$\bar{y} = 3r/8$
$\bar{I} = 83mr^2/320$
$I_x = 2mr^2/5$
$I_y = 2mr^2/5$

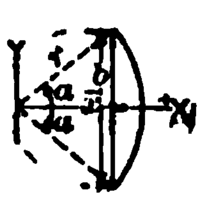

Fig. 27

$A = r^2(a - \frac{1}{2}\sin 2a^\circ)$
$\bar{x} = (b^3 - 8r^3 \sin^3 a^\circ)/12A$
$I_x = \frac{1}{4}Ar^2 \dfrac{(1 - \frac{2}{3}\sin^3 a^\circ \cos a^\circ)}{(a - \sin a^\circ \cos a^\circ)}$
$I_y = \frac{1}{4}Ar^2 \dfrac{1 + 2\sin^3 a^\circ \cos a^\circ)}{(a - \sin a^\circ \cos a^\circ)}$

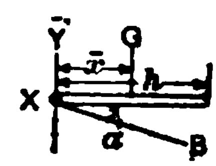

Fig. 28

$V = Ah$
$\bar{x} = \frac{1}{2}h$
$\bar{I} = mh^2/12$
$I_y = mh^2/3$
$I_B = mh^2 \sin a^\circ/3$

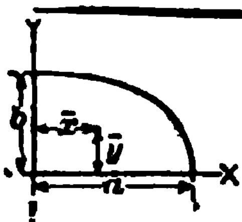

Fig. 29

$A = \frac{1}{4}\pi ab$
$\bar{x} = 4a/3\pi;\ \bar{y} = 4b/3\pi$
$I_x = \pi ab^3/16 = Ab^2/4$
$I_y = \pi ba^3/16 = Aa^2/4$
$I_z = \pi ab(a^2+b^2)/16$

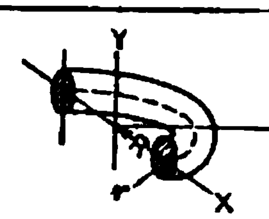

Fig. 30

$V = \pi^2 Rr^2$
$\bar{x} = 2R/\pi$*
$I = m(4R^2+3r^2)/4$
$I = m(4R^2+5r^2)/8$
*App. for r small

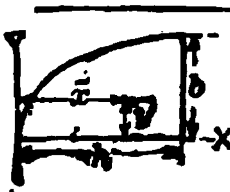

Fig. 31

$A = 2bh/3$
$\bar{x} = 3h/5;\ \bar{y} = 3b/8$
$I_x = 2hb^3/15$
$I_y = 2bh^3/7$

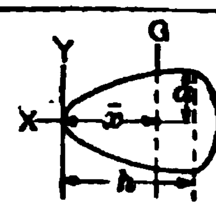

Fig. 32

$V = \frac{1}{2}\pi a^2 h$
$\bar{x} = 2h/3$
$\bar{I} = m(h^2+3a^2)/18$
$I_x = ma^2/3$
$I_y = m(3h^2+a^2)/6$

of mass per unit volume, or, in symbols $\delta = W/gV$, so that for any given material $m = \delta V = W/g$. The moment of inertia of a mass, or area, with respect to any axis is equal to its moment of inertia with respect to a parallel axis thru the center of gravity, plus the product of the mass, or area, and the square of the distance between the axes. The moment of inertia of a compound mass, or area, with respect to any required axis, is equal to the sum of the moments of inertia of its parts with respect to that axis. If X, Y and Z are three mutually perpendicular axes, and any given area is in the X Y plane, then I_x and I_y are called the rectangular moments of inertia and I_z is called the polar moment of inertia, sometimes represented by J. For such a case $J = I_z = I_x + I_y$, gives a convenient relation between these moments. The moment of inertia of any thin plate, with respect to an axis in its face or perpendicular to it, is equal to the density, times the thickness, times the moment of inertia of the face area with respect to the same axis. In Table II, a is measured in radians, and $a°$ in degrees, one radian = 57.°296; 1° = 0.0175 radians.

Typical Problem. To determine the moment of inertia of any compound section area with respect to a horizontal gravity axis, divide the given area into simple part areas for which $\bar{I}$ and y are known, and apply the formulas $\bar{y} = \Sigma Ay/\Sigma A$, and $I = \bar{I} + Ad^2$, tabulating the solution as shown.

In this case the given channel section may be divided into three rectangles and two triangles for which the values of $\bar{I}$ are given in Table II.

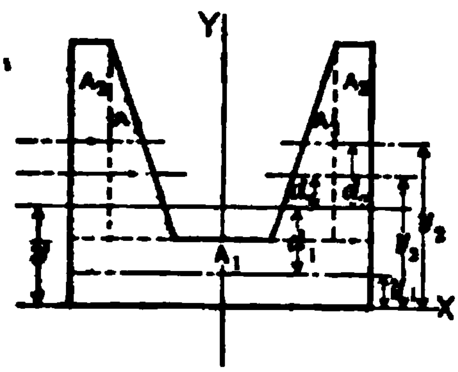

Fig. 33

A	y	Ay	d^2	Ad^2	$\bar{I}$
$A_1 = 18$	1	18	4	72	6
$2A_2 = 12$	5	60	4	48	18
$2A_3 = 12$	4	48	1	12	12
42		126		132	36
	$\bar{y} =$	3			132
				$\bar{I} =$	168 in.^{4}

10. Stress and Strain

Definitions. STRESS is a name given to the distributed force within a body which is brought into play by the action of external forces upon the body. The accompanying change of shape, or deformation, is called STRAIN. The ratio of the total linear deformation to the original length is called the UNIT STRAIN, or RELATIVE STRAIN, and the rate of distribution of the stress over the area is called the UNIT STRESS, or the STRESS INTENSITY, $S = P/A$, for uniform distribution. The greatest unit stress to which a body may be subjected without producing a permanent deformation, or SET, is called the ELASTIC LIMIT; the greatest unit stress to which a body can be subjected is called the ULTIMATE LIMIT; and the intensity of stress at which the body breaks is called the RUPTURE LIMIT; these intensities being figured in terms of the original section area. For most materials these last two limits are identical.

Fundamental Relations. (1) The external forces and internal stresses acting on any part of a material body, or a framed structure, form a balanced system. (2) Within the elastic limit, the ratio of the unit stress to the unit strain is a constant called the MODULUS OF ELASTICITY for the material. The stress may act in any direction with respect to the area over which it is distributed, but it can always be replaced by rectangular components,

respectively normal and tangential to the surface. The normal component is called a pure TENSION, or a pure COMPRESSION, according as it acts toward or away from the surface, while the tangential component is called a pure SHEARING STRESS.

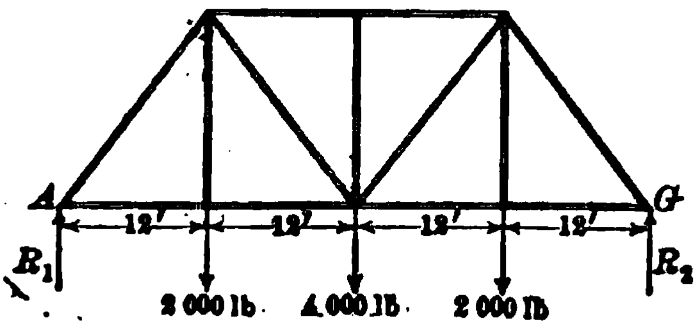

Fig. 34

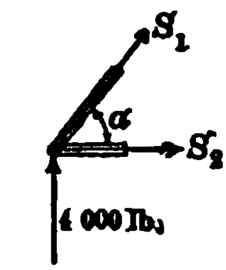

Fig. 35

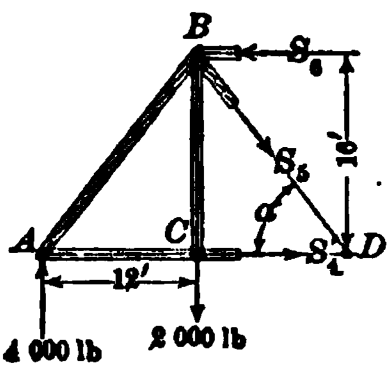

Fig. 36

Axial Stresses in Trusses. In the usual discussion of simple frameworks or trusses it is assumed that the members are subjected only to axial stresses, that the members are pin-connected at all joints and that the loads and reactions are applied at the joints. In order to solve for the unknown reactions and member stresses in any truss, it is simply necessary to see that the external loads and reactions form a balanced system, usually parallel, that the external forces and the stresses in the members acting, at any joint, form a balanced concurrent system, and that the external forces and the stresses in the members, acting on any portion of the truss, form a balanced nonconcurrent system. The application of the appropriate conditions of equilibrium, (see Art. 8), furnishes a solution, either algebraic or graphic, for the unknown reactions and member stresses.

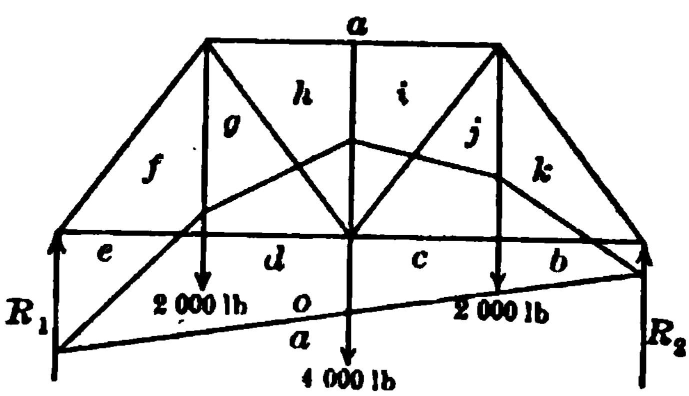

Fig. 37

Algebraic Method. In Fig. 34, for the external loads and reactions, $\Sigma P = R_1 + R_2 - 2000 - 4000 - 2000 = 0$, $M_G = 48R_1 - 12 \times 2000 - 24 \times 4000 - 36 \times 2000 = 0$, giving $R_1 = 4000$ lb and $R_2 = 4000$ lb. In Fig. 35, for the concurrent system at the first joint, since $\sin\alpha = 4/5$ and $\cos\alpha = 3/5$, $\Sigma P_y = 4000 - (4/5)S_1 = 0$ gives $S_1 = 5000$ lb, $\Sigma P_x = S_2 - (3/5)S_1 = 0$ gives $S_2 = 3000$ lb. In Fig. 36 for the nonconcurrent system which holds the triangle ABC in equilibrium, $M_D = 24 \times 4000 - 12 \times 2000 - 16S_6 = 0$, $S_6 = 4500$ lb. $M_B = 12 \times 4000 - 16S_4 = 0$, $S_4 = 3000$ lb, $\Sigma P_y = 4000 - 2000 - (4/5)S_5 = 0$, $S_5 = 2500$ lb. The stress in the first vertical is obviously 2000 lb, and in the second vertical it is zero. The moment equations should be written with respect to the points where the action lines of any two unknown stresses intersect. If it is not possible to tell by inspection whether the action of any member, at a joint, is a push or a pull, the corresponding stress in the member being compression or tension, assume it to be positive. If the solution gives a negative value, the assumption must be revised. The stresses S_1 and S_6 are compression, the others are tension.

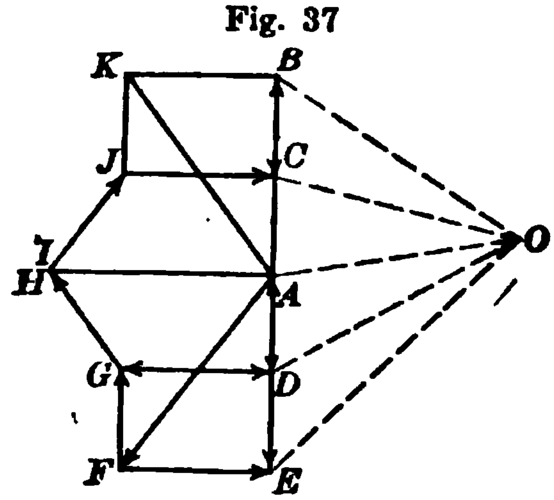

Fig. 38

Graphic Method. In order to find the unknown reactions and member stresses for the given truss loaded as shown in Fig. 26, it is first necessary to letter the truss,

giving a letter to each space enclosed by the action lines of the external forces or the internal stresses. Then draw the force polygon, *BCDE*, for the external loads, select a convenient pole *O*, and draw the rays *ob*, *oc*, *od* and *oe* (see Fig. 38). Starting on R_2 (see Fig. 37), run in the string polygon to R_1, and draw the closing string *oa*. In the force polygon the corresponding ray may now be drawn to determine the point *A*, such that *EA* represents the magnitude of R_1, and *AB*, the magnitude of R_2. Then, beginning at either end of the truss, draw the closed force polygons for the concurrent systems of forces at the joints, taken in order; starting in each case with the forces or stresses that are known in magnitude. The kind of stress is determined by noting the direction in which the stress acts with respect to the joint at which it is applied. For example, the stress polygon for the middle lower joint is *CDGHIJC*, the direction of these forces being indicated on the force polygon. If these are imagined to be applied at the joint, in their respective action lines, it will be seen that they act away from the joint, indicating that these members are all in tension. Since the points *H* and *I* are coincident, the stress in the middle vertical must be zero.

Vertical Shear, with respect to any vertical section of a beam or truss, is a name given to the algebraic sum of the external vertical forces to the left of the section, upward forces being considered positive. A similar summation to the right of the section will have the same numerical value but the opposite algebraic sign. The vertical shear, for any beam or truss, may be graphically represented by the ordinates of the SHEAR CURVE, the corresponding abscissas being the distances of the sections from the end of the span. A typical SHEAR DIAGRAM is shown in Fig. 39a.

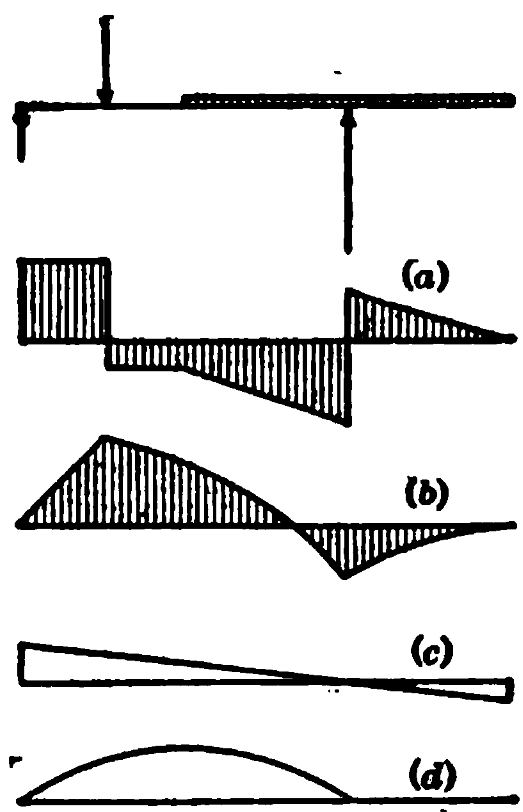

Fig. 39

Bending Moment, with respect to any section, is a name given to the algebraic sum of the moments of the forces to the left of the section, written with respect to an axis at the section, clockwise moments being considered positive. A similar summation to the right of the section will have the same numerical value but the opposite algebraic sign. The bending moment at any section may be graphically represented by the corresponding ordinate of the MOMENT CURVE. A typical MOMENT DIAGRAM is shown in Fig. 39b. It should be carefully noted that the vertical shear is always zero for any section with respect to which the bending moment is maximum.

Influence Lines, for shear or moment, are graphical representations of the change in the vertical shear or the bending moment at any section, produced by a unit load placed at that section, the ordinates of the line representing the change; the abscissas being, in each case, the distance of the section from the end of the span. See Figs. 39c and Fig. 39d.

Stresses in Beams. The tension or the compression component of the flexural stress intensity in any fiber of a loaded beam varies directly with the distance from a horizontal sheet of fibers, called the NEUTRAL SURFACE, which is neither stressed nor strained. This neutral surface intersects the vertical section in a line, called the NEUTRAL AXIS, which passes thru the center of gravity of the section. The component shear intensity is usually assumed to be constant over the vertical section and equal to the vertical shear divided by the area of the section, $S_s = V/A$. The actual intensity of the horizontal or vertical shearing stress in a beam, along any line

parallel to a neutral axis, is given by the formula, $S_s = \frac{V}{Ib} A\bar{z}$, where V is the vertical shear for the section, I is the moment of inertia of the section area with respect to the neutral axis, b is the width of the section at the line in question, A is the section area above the line, and $\bar{z}$ is the distance of the center of gravity of this area from the neutral axis of the section. The total moment of the stress on any section, with respect to the neutral axis, is given by SI/c, and is always equal to the bending moment for the section. The maximum intensity of the tensile or compressive stress in the beam is found in the outer fiber at the section where the bending moment is maximum. This maximum unit stress, S, and the maximum deflection, f, are given by the formulas, $S = \alpha \frac{Plc}{I}$ and $f = \beta \frac{Pl^3}{EI}$, where P is the whole load, $P = wl$ for a uniformly distributed load, l is the whole length, I is the moment of inertia of the section area with respect to the neutral axis, c the distance of the section fiber from the neutral surface and E is the modulus of elasticity of the material. The values of α and β for the simple types of beams and loadings are given in the following table, where k is a fraction, such that kl represents the distance of a concentrated load from the left support, or from the free end of a cantilever.

Beam	Load	α	β
Fixed at one end, cantilever	Concentrated	$(1-k)$	$(2-3k+k^3)/6$
	Distributed	1/2	1/8
Supported at both ends	Concentrated, $k \overline{\overline{>}} \frac{1}{2}$	$(1-k)k$	$(1-k)(2k/3-k^2/3)^{\frac{3}{2}}/3$
	Distributed	1/8	5/384
Right end fixed, left supported	Concentrated, $k = \frac{1}{2}$	3/16	0.0102
	Distributed	1/8	0.0054
Fixed at both ends	Concentrated, $k = \frac{1}{2}$	1/8	1/192
	Distributed	1/12	1/384

The maximum unit stress, or deflection, at any section, due to a system of loads, is simply the sum of the effects produced, at that section, by the separate loadings; but, since each load may produce its maximum effect at a different section, the determination of the absolute maximums for the beam is frequently a complicated problem.

Stresses in Round Shafts. When a round shaft is subjected to a twisting action, shearing stresses are induced on every cross-section, and the intensity of this shearing stress is proportional to the distance from the axis of the shaft. The total moment of the stress on any section, with respect to the axis of the shaft, is given by SJ/r, and is equal to the external twisting moment. The maximum unit shearing stress and the total angle of twist are given by the following equations: $S = Mr/J = 321\,000\ H/nd^3$ and $\phi = 57.3\ Ml/E_sJ = 3\,610\,000\ Hl/nE_sJ$, where M is the twisting moment, J is the polar moment of inertia of the cross-section area, l is the length of the shaft, ϕ is the angle, in degrees, thru which one end is twisted with respect to the other, r is the radius and d the diameter of the shaft, E_s is the modulus of elasticity for shearing, H is the horse-power transmitted by the shaft and n is the number of revolutions it makes per minute. Since S_s and E_s are expressed in pounds per square inch, all the linear dimensions must be taken in inches.

Stresses in Columns. If a short block is subjected to an axial load, the relation between the load and the unit stress induced is given by the formula $P/A = S$, but when the length becomes so great, in comparison with the

cross-section, that the stress is no longer pure compression, the determination of this relation is neither simple nor exact. Three general types of column formulas have been derived relating to the load P, the cross-section area A, the length l, and the least radius of gyration k.

Euler's Formula, which is historically the first, may be stated in general form as $P/A = \mu E(k/l)^2$, where E is the modulus of elasticity and μ is a constant depending on the end conditions of the column. The formula is not exact, except for very long and slender columns, and is rarely used. Since P is a rupture load, it must be divided by a factor of safety.

Rankine's Formula, which was formerly much used, is generally stated as $P/A = S/(1 + \phi\,(l/k)^2)$, where S is usually taken as the ultimate unit compressive stress for the material and ϕ is an experimental constant depending upon the material and the end conditions of the column. Either P or S must be divided by a factor of safety to give the safe load.

Straight Line Formulas, which are preferred at the present time, are of the general type $P/A = S - C(l/k)$, and were suggested by a study of the plotted results of column experiments, in connection with a similar plot of Euler's equation. The locus of the experimental points was observed to approximate much more closely to a straight line tangent to the Euler curve, than to the curve itself, and the equation of such a straight line was adopted as a column formula. The values of the experimental constants S and C are usually prescribed by the specifications for any particular condition.

Impact Stresses. In all the preceding discussion of stresses, it was assumed that the load was gradually applied so that the stress increased uniformly to its maximum value, and such stresses are called dead load, or static stresses. The same load, if applied suddenly, or with a velocity, as by a blow, or even in a finite short time, as with a rolling load, will produce impact stresses which are greatly in excess of the static stresses. The stresses due to the live load on a truss are usually figured by the method outlined in a preceding paragraph, for dead load stresses, and then multiplied by an impact factor of the form $(1 + i)$, where i has some value between zero and one, dependent on the velocity of the moving load and other practical considerations. For the value of this impact factor, consult specifications. In the designing of trusses this impact effect may be taken into account by assuming a much lower allowable unit stress for live load than for dead load stresses.

Fatigue. The word fatigue is used to describe the loss of molecular strength, or the impairment of the elastic properties, of a material by reason of the rapid or frequent variation of the intensity of stress to which it is subjected. The rupture limit is assumed to be the unit stress which would rupture the material at one application, but experiments show that rupture may be produced by a unit stress considerably below this value if applied a great number of times, and the greater the range between the maximum and minimum stresses, especially if the change is from tension to compression, the less the value of the maximum stress required to produce rupture. In the designing of members subjected to varying stresses, this effect may be taken into account, either by lowering the allowable unit stress or assuming an increment to the load. In bridge design if the allowable unit stress is not greater than half the elastic limit, the question of fatigue need not be considered, but it should not be ignored in the design of machine parts which are subjected to shock.

11. Kinetics

Fundamental Rates. The time rate of linear displacement of a point, or of angular displacement of a line, is called velocity, linear or angular,

and the time rate of change of velocity is called ACCELERATION, also linear or angular. Expressed in symbolic form, $v = ds/dt$, $\omega = d\theta/dt$, $a = dv/dt$ and $\alpha = d\omega/dt$. The integration of these differential relations, between limits determined by initial and final conditions, will give the following important finite relations, for the special case of a and α constant:

$$v = v_0 + at \qquad v^2 = v_0^2 = 2as \qquad s = v_0t + \tfrac{1}{2}at^2$$
$$\omega = \omega_0 + \alpha t \qquad \omega^2 = \omega_0^2 + 2\alpha\theta \qquad \theta = \omega_0 t + \tfrac{1}{2}\alpha t^2$$

where v_0, or ω_0, is the value of the velocity when t and s, or θ, are simultaneously zero. Since any point in a rotating line moves thru a linear arc, $ds = r\,d\theta$, while the line turns thru the angle $d\theta$, it follows that $ds/dt = r\,d\theta/dt$, that is $v = r\omega$, and also $a = r\alpha$, are the fundamental relations between the angular motion of a line and the linear motion of any point in it, r being the distance of the point in question from the instantaneous center of rotation.

Motion of a Particle. The fundamental law of motion states that, if a particle is acted upon by any concurrent system of forces, an acceleration is produced, in the direction of the resultant force, directly proportional to its magnitude, and inversely proportional to the mass of the particle. Stated in symbols, $a = R/m$. If $R = 0$, then $a = 0$, and the particle is at rest or moving in a straight line with a constant velocity. Such a motion is called UNIFORM. If R is constant, them a is constant, and if the particle was initially at rest or moving in the direction of the resultant force, the motion will be UNIFORMLY ACCELERATED, rectilinear motion, to which the relations, derived in the preceding paragraph may be applied. If the resultant force is not in the direction of the initial velocity, or if its direction changes with time, the resulting motion will be curvilinear, and the resultant force will have a central component, normal to the path, which is always equal to mv^2/r, and a tangential component equal to ma_t, where v is the path velocity, a_t is its acceleration, and r is the radius of curvature of the path. The resistance which the particle offers to the action of this central component is commonly called the centrifugal force of the particle.

Motion of a Body. By the methods outlined in Art. 8, any system of forces acting on a body may be reduced to a single force, or to a couple, or to a force and a couple; and it should be noted that a single force acting at any point in a body is equivalent to an equal, parallel force at the center of gravity and a couple, whose moment is the product of the force and the perpendicular distance from the center of gravity to its action line. If the body is initially at rest, the resulting motion will be a plane motion except when the force and the couple act in different planes. Any plane motion may be treated as a rotation about any axis perpendicular to the plane combined with a translational motion of that axis, or it is instantaneously a motion of pure rotation with respect to a particular axis called the INSTANTANEOUS AXIS. The equations of any plane motion are,

$$\Sigma P_x = ma_x - \alpha\bar{y}m - \omega^2\bar{x}m$$
$$\Sigma P_y = ma_y + \alpha\bar{x}m - \omega^2\bar{y}m$$
$$M_z = \alpha I - a\bar{y}m$$

where ΣP_x and ΣP_y are the sums of the external force components parallel to the respective axes, M_z is the external force moment with respect to the Z axis, a is the resulting linear acceleration of the axis of rotation, a_x and a_y are its axial components, α is the angular acceleration and ω the angular velocity of the body. The Z axis must coincide with the axis of rotation, the XY plane must be a plane of symmetry for the body, and I is the mass moment of inertia of the body with respect to the axis of rotation. If the

origin of coördinates is taken at the center of gravity of the body, then $\bar{x}$ and $\bar{y}$ are zero; and if the axis of rotation is fixed, or moving with a constant velocity in a right line, a is also zero, so that these equations may be much simplified for most problems. The following important special cases deserve particular attention.

Case 1. Pure Translation. If the resultant of the external system is a single force at the center of gravity, the body has a motion of pure translation with a linear acceleration, $a = R/m$, which is the same for all particles. If a is constant, the linear relations, derived in the first paragraph of this article, may be directly applied, and the substitution of R/m for a in the first two will give, $mv - mv_0 = Rt$ and $\frac{1}{2}mv^2 - \frac{1}{2}mv_0^2 = Rs$ or, change in LINEAR MOMENTUM is equal to IMPULSE and change in KINETIC ENERGY of translation is equal to WORK, these being the accepted names for the related products, taken in order. WORK is exactly defined as the product of a force and the distance its point of application moves in the direction of the force, while KINETIC ENERGY represents stored work, or the ability to do work by virtue of motion.

Case 2. Pure Rotation. If the resultant of the external force system is a couple, the body will have a motion of pure rotation about an axis thru the center of gravity or about some fixed axis, with an angular acceleration, $\alpha = M_z/I$. If α is constant, the angular relations, derived in the first paragraph of this article, are directly applicable, and the substituion of M_z/I for α in the first two will give, $I\omega - I\omega_0 = M_zt$ and $\frac{1}{2}I\omega^2 - \frac{1}{2}I\omega_0^2 = M_z\theta$ or, change in ANGULAR MOMENTUM is equal to the IMPULSE MOMENT, and change in KINETIC ENERGY of rotation is equal to the WORK done in rotation, these being the accepted names for the related products, taken in order.

Case 3. Pure Rolling. If the external force system reduces to a force at the center of gravity and a couple, such that $a = r\alpha$, the body having a circular cross-section of radius r, the resulting motion is pure rolling, for which the total kinetic energy is equal to $\frac{1}{2}mv^2 + \frac{1}{2}I\omega^2$. If the body is rolling down an incline under the action of gravity, then $a = g \sin \phi/(1 + k^2/r^2)$, where g is the acceleration due to gravity, k is the radius of gyration of the rolling mass, and ϕ is the angle which the incline makes with the horizontal.

Power is defined as the time rate at which a force is doing work, and is represented by dW/dt or by Pv, where W is the work, P is the force and v is the velocity of its point of application. It is measured in terms of inch-pounds, foot-pounds, inch-tons, foot-tons or horse-power, where ONE HORSE-POWER is the equivalent of 550 ft-lb per sec, or 33 000 ft-lb per min.

Impact. When a force is suddenly applied, the action is called an IMPACT or a BLOW. If the impact is produced by one moving body striking another, an interchange of velocity takes place and some kinetic energy is lost, but the total momentum of the system is unchanged. If the centers of gravity are moving in the same direction and in the same straight line, and if the surfaces of contact are perpendicular to this line, the velocities after impact and the kinetic energy loss are given by,

$$v_1' = v_1 + (1 + e)\, m_2(v_2 - v_1)/(m_1 + m_2)$$
$$v_2' = v_2 - (1 + e)\, m_1(v_2 - v_1)/(m_1 + m_2)$$
$$\text{LOST K. E.} = \tfrac{1}{2}\, m_1m_2(1 - e^2)(v_2 - v_1)^2/(m_1 + m_2)$$

where v_1 and v_2 are the velocities of the masses m_1 and m_2 before impact, v_1' and v_2' are the corresponding velocities after impact and e is an elastic constant whose value is zero for inelastic bodies, one for perfectly elastic bodies, and some intermediate value for partially elastic bodies.

STRUCTURAL MATERIALS

12. Cement

Kinds. From an engineering standpoint, cements may be divided into PORTLAND, NATURAL and PUZZOLAN. Common lime and hydraulic lime may also be included, but as materials of construction for the highway engineer are

of secondary importance. Common lime requires air in which to harden, while the other kinds are hydraulic, that is, they will harden under water. Altho natural and Puzzolan cements are much cheaper than Portland, the latter is used in most engineering construction on account of its more uniform properties of strength and soundness which give more confidence in its durability. Portland cement can also be mixed with larger proportions of sand and gravel, which tends to equalize the cheapness of the other kinds and to make the final results economical. Natural cement is sometimes used in the less important work where little strength is required, such as mass concrete, foundations for street pavements, and footings where it is desired to increase the bearing power of the soil.

Portland Cement is the product of calcination to incipient fusion of argillaceous and calcareous materials. The raw material consists chiefly of calcium carbonate and silicate of alumina, proportioned according to their chemical composition. They must be ground to a powder and mixed before burning, after which the resulting clinker must be finely ground according to standard specifications.

Natural Cement is the product of calcination, at a comparatively low temperature of a natural argillaceous limestone. The rock is broken in small pieces and burned in a kiln, after which grinding takes place, the resulting powder being less fine than Portland.

Puzzolan Cement was formerly of volcanic origin, and was probably the first hydraulic cement used by man. In recent years this name has been given to a cement made by grinding together granulated blast furnace slag and powdered slacked lime, without calcination.

Common Lime is obtained by the calcination of a limestone which is nearly pure carbonate of lime. It will not set under water and will slack on the addition of water.

Hydraulic Lime is obtained from limestone which has from 10 to 20% of silica and alumina and differs from common lime in that it will set under water. It is not used in the United States.

Typical Analyses of cements, as given by Taylor and Thompson (54), are shown in Table III.

Table III.—Typical Percentage Analyses of Cements

	Portland Cement		Natural Cement		Puzzolan Cement	Hydraulic Lime, Le Tiel	Common Lime	
	Lehigh Valley Mixed Rock	Western Marl and Clay	Eastern Rosendale	Western Louisville			Lime	Magnesian Lime
Silica, SiO_2	21.31	21.93	18.38	20.42	28.95	21.70	1.03	1.12
Alumina, Al_2O_3	6.89	5.98	15.20 (Alumina and iron oxide)	4.76	11.40	3.19	1.27 (Alumina and iron oxide)	0.68
Iron oxide, Fe_2O_3	2.53	2.35		3.40	0.54	0.66		....
Calcium oxide, CaO	62.89	62.92	35.84	46.64	50.29	60.70	97.02	58.51
Magnesian oxide, MgO	2.64	1.10	14.02	12.00	2.96	0.85	0.68	39.69
Sulphuric acid, SO_3	1.34	1.54	0.93	2.57	1.37	0.60	.....	.....
Loss on ignition	1.39	2.91	3.73	6.75	3.39	12.20	.....	.....
Other constituents	0.75	.....	11.46	3.74	0.30	0.10	.....	.....

The Manufacture of Portland Cement consists of obtaining the raw material as it exists in nature and properly combining it according to its chemical composition, crushing and grinding the mixture, after which it is calcined, cooled, ground to powder and packed. The raw materials in most common use include limestone, argillaceous limestones, cement rocks and marl, and all contain what is known as the lime limit. To all of these except the cement rocks, clay or shale must be mixed to produce the argillaceous requirement. It is necessary to add lime to the cement rocks in order to bring the material up to the proper lime limit. The materials may be mixed dry or wet, usually depending upon the ingredients used. For burning, stationary and rotary kilns are in use, the latter being the more modern.

The Methods for Testing Cement to see that it conforms to specifications are usually those adopted by the Am. Soc. C. E. (62a) and by the Am. Soc. Test. Mat. In all work of any magnitude, the cement used should be tested. Where only a limited amount of cement is used, a standard brand may be taken without testing, or only a part of the tests made; such as the tests for soundness and time of setting, which may be made without much equipment. It should be noted that tests of cement are relative and not absolute, and that the results of such tests differ widely in the hands of different operators, especially for those who are inexperienced in making them. Negative results should therefore be studied with care and checks applied to determine their reliability before rejecting the cement.

Am. Soc. Test. Mat. Standard Specifications and Tests for Portland Cement, as revised in 1916 (63 l).

"1. **Definition.** Portland cement is the product obtained by finely pulverizing clinker produced by calcining to incipient fusion, an intimate and properly proportioned mixture of argillaceous and calcareous materials, with no additions subsequent to calcination excepting water and calcined or uncalcined gypsum.

"2. **Chemical Properties.** The following limits shall not be exceeded:

Loss on ignition, percent	4.00
Insoluble residue, percent	0.85
Sulphuric anhydride, SO_3, percent	2.00
Magnesia, MgO, percent	5.00

"3. **Physical Properties.** The SPECIFIC GRAVITY of cement shall be not less than 3.10, 3.07 for white Portland cement. Should the test of cement as received fall below this requirement a second test may be made upon an ignited sample. The specific gravity test will not be made unless specifically ordered.

"4. FINENESS. The residue on a standard No. 200 sieve shall not exceed 22% by weight.

"5. SOUNDNESS. A pat of neat cement shall remain firm and hard, and show no signs of distortion, cracking, checking, or disintegration in the steam test for soundness.

"6. TIME OF SETTING. The cement shall not develop initial set in less than 45 min when the Vicat needle is used or 60 min when the Gillmore needle is used. Final set shall be attained within 10 hr.

"7. TENSILE STRENGTH. The average tensile strength in pounds per square inch of not less than 3 standard mortar briquettes (see Par. 51) composed of 1 part cement and 3 parts standard sand, by weight, shall be equal to or higher than the following:

Age at Test, Days	Storage of Briquettes	Tensile Strength, Lb per Sq In
7	1 day in moist air, 6 days in water	200
28	1 day in moist air, 27 days in water	300

"8. The average tensile strength of standard mortar at 28 days shall be higher than the strength at 7 days.

"9. **Packages, Marking and Storage.** The cement shall be delivered in suitable bags or barrels with the brand and name of the manufacturer plainly marked thereon unless shipped in bulk. A bag shall contain 94 lb net. A barrel shall contain 376 lb net.

"10. The cement shall be stored in such a manner as to permit easy access for proper inspection and identification of each shipment, and in a suitable weather-tight building which will protect the cement from dampness.

"11. **Inspection.** Every facility shall be provided the purchaser for careful sampling and inspection at either the mill or at the site of the work, as may be specified by the purchaser. At least 10 days from the time of sampling shall be allowed for the completion of the 7-day test, and at least 31 days shall be allowed for the completion of the 28-day test. The cement shall be tested in accordance with the methods hereinafter prescribed. The 28-day test shall be waived only when specifically ordered.

"12. **Rejection.** The cement may be rejected if it fails to meet any of the requirements of these specifications.

"13. Cement shall not be rejected on account of failure to meet the fineness requirement if upon retest after drying at 100° C (212° F) for 1 hr it meets this requirement.

"14. Cement failing to meet the test for soundness in steam may be accepted if it passes a retest using a new sample at any time within 28 days thereafter.

"15. Packages varying more than 5% from the specified weight may be rejected; and if the average weight of packages in any shipment, as shown by weighing 50 packages taken at random, is less than that specified, the entire shipment may be rejected.

"16. **Tests.** NUMBER OF SAMPLES. Tests may be made on individual or composite samples as may be ordered. Each test sample should weigh at least 8 lb.

"17. *a. Individual Sample.* If sampled in cars one test sample shall be taken from each 50 bbl or fraction thereof. If sampled in bins one sample shall be taken from each 100 bbl.

b. Composite Sample. If sampled in cars one sample shall be taken from one sack in each 40 sacks, or 1 bbl in each 10 bbl, and combined to form one test sample. If sampled in bins or warehouses one test sample shall represent not more than 200 bbl.

"18. METHOD OF SAMPLING. Cement may be sampled at the mill by any of the following methods that may be practicable, as ordered:

a. From the Conveyor Delivering to the Bin. At least 8 lb of cement shall be taken from approximately each 100 bbl passing over the conveyor.

b. From Filled Bins by Means of Proper Sampling Tubes. Tubes inserted vertically may be used for sampling cement to a maximum depth of 10 ft. Tubes inserted horizontally may be used where the construction of the bin permits. Samples shall be taken from points well distributed over the face of the bin.

c. From Filled Bins at Points of Discharge. Sufficient cement shall be drawn from the discharge openings to obtain samples representative of the cement contained in the bin, as determined by the appearance at the discharge openings of indicators placed on the surface of the cement directly above these openings before drawing of the cement is started.

"19. TREATMENT OF SAMPLE. Samples preferably shall be shipped and stored in air-tight containers. Samples shall be passed thru a 20-mesh sieve in order to thoroly mix the sample, break up lumps and remove foreign materials.

"20. **Chemical Analysis.** LOSS ON IGNITION. One gram of cement shall be heated in a weighed covered platinum crucible, of 20 to 25-cc capacity, as follows, using either method (*a*) or (*b*) as ordered:

a. The crucible shall be placed in a hole in an asbestos board, clamped horizontally so that about $^3/_5$ of the crucible projects below, and blasted at a full red heat for 15 min with an inclined flame; the loss in weight shall be checked by a second blasting for 5 min. Care shall be taken to wipe off particles of asbestos that may adhere to the crucible when withdrawn from the hole in the board. Greater neatness and shortening of the time of heating are secured by making a hole to fit the crucible in a circular disk of sheet platinum and placing this disk over a somewhat larger hole in an asbestos board.

b. The crucible shall be placed in a muffle at any temperature between 900° and

1000° C (1652° and 1832° F) for 15 min and the loss in weight is checked by a second heating for 5 min.

"21. A PERMISSIBLE VARIATION of 0.25 will be allowed, and all results in excess of the specified limit but within this permissible variation shall be reported as 4%.

"22. **Insoluble Residue.** To a 1-g sample of cement shall be added 10 cc of water and 5 cc of concentrated hydrochloric acid; the liquid shall be warmed until effervescence ceases. The solution shall be diluted to 50 cc and digested on a steam bath or hot plate until it is evident that decomposition of the cement is complete. The residue shall be filtered, washed with cold water, and the filter paper and contents digested in about 30 cc of a 5% solution of sodium carbonate, the liquid being held at a temperature just short of boiling for 15 min. The remaining residue is filtered, washed with cold water, then with a few drops of hot hydrochloric acid, 1 : 9, and finally with hot water, and then ignited at a red heat and weighed as the insoluble residue.

"23. A PERMISSIBLE VARIATION of 0.15 will be allowed, and all results in excess of the specified limit but within this permissible variation shall be reported as 0.85%.

"24. **Sulphuric Anhydride.** One gram of the cement is dissolved in 5 cc of concentrated hydrochloric acid diluted with 5 cc of water, with gentle warming; when solution is complete 40 cc of water are added, the solution is filtered, and the residue washed thoroly with water. The solution is diluted to 250 cc, heated to boiling and 10 cc of a hot 10% solution of barium chloride shall be added slowly, drop by drop, from a pipette and the boiling continued until the precipitate is well formed. The solution shall be digested on the steam bath until the precipitate has settled. The precipitate shall be filtered, washed, and the paper and contents placed in a weighed platinum crucible and the paper slowly charred and consumed without flaming. The barium sulphate shall then be ignited and weighed. The weight obtained multiplied by 34.3 gives the percentage of sulphuric anhydride. The acid filtrate obtained in the determination of the insoluble residue may be used for the estimation of sulphuric anhydride instead of using a separate sample.

"25. PERMISSIBLE VARIATION. A permissible variation of 0.10 will be allowed, and all results in excess of the specified limit but within this permissible variation shall be reported as 2%.

"26. **Magnesia.** To 0.5 g of the cement in an evaporating dish shall be added 10 cc of water to prevent lumping and then 10 cc of concentrated hydrochloric acid. The liquid shall be gently heated and agitated until attack is complete. The solution shall then be evaporated to complete dryness on a steam or water bath. To hasten dehydration the residue may be heated to 150° C (302° F) or even 200° C (392° F) for ½ to 1 hr. The residue shall be treated with 10 cc of concentrated hydrochloric acid diluted with an equal amount of water. The dish shall be covered and the solution digested for 10 min on a steam bath or water bath. The diluted solution shall be filtered and the separated silica washed thoroly with water.* Five cubic centimeters of concentrated hydrochloric acid and sufficient bromine water to precipitate any manganese which may be present, shall be added to the filtrate, about 250 cc. This shall be made alkaline with ammonium hydroxide, boiled until there is but a faint odor of ammonia, and the precipitated iron and aluminum hydroxides, after settling, shall be washed with hot water, once by decantation and slightly on the filter. Setting aside the filtrate, the precipitate shall be transferred by a jet of hot water to the precipitating vessel and dissolved in 10 cc of hot hydrochloric acid. The paper shall be extracted with acid, the solution and washings being added to the main solution. The aluminum and iron shall then be reprecipitated at boiling heat by ammonium hydroxide and bromine water in a volume of about 100 cc, and the second precipitate shall be collected and washed on the filter used in the first instance if this is still intact. To the combined filtrates from the hydroxides of iron and aluminum, reduced in volume if need be, 1 cc of ammonium hydroxide shall be added, the solution brought to boiling, 25 cc of a saturated solution of boiling ammonium oxalate added, and the boiling continued until the precipitated calcium oxalate has assumed a well-defined granular form. The precipitate after 1 hr shall be filtered and washed, then with the filter shall be placed wet in a platinum crucible, and the paper burned off over a

*Since this procedure does not involve the determination of silica, a second evaporation is unnecessary.

small flame of a Bunsen burner; after ignition it shall be redissolved in hydrochloric acid and the solution diluted to 100 cc. Ammonia shall be added in slight excess, and the liquid boiled. The lime shall then be reprecipitated by ammonium oxalate, allowed to stand until settled, filtered and washed. The combined filtrates from the calcium precipitates shall be acidified with hydrochloric acid, concentrated on the steam bath to about 150 cc, and made slightly alkaline with ammonium hydroxide, boiled and filtered, to remove a little aluminum and iron and perhaps calcium. When cool, 10 cc of saturated solution of sodium-ammonium-hydrogen phosphate shall be added with constant stirring. When the crystalline ammonium-magnesium orthophosphate has formed, ammonia shall be added in moderate excess. The solution shall be set aside for several hours in a cool place, filtered and washed with water containing 2.5% of NH_3. The precipitate shall be dissolved in a small quantity of hot hydrochloric acid, the solution diluted to about 100 cc, 1 cc of a saturated solution of sodium-ammonium-hydrogen phosphate added, and ammonia drop by drop, with constant stirring, until the precipitate is again formed as described and the ammonia is in moderate excess. The precipitate shall then be allowed to stand about 2 hr, filtered and washed as before. The paper and contents shall be placed in a weighed platinum crucible, the paper slowly charred, and the resulting carbon carefully burned off. The precipitate shall then be ignited to constant weight over a Meker burner, or a blast not strong enough to soften or melt the pyrophosphate. The weight of magnesium pyrophosphate obtained multiplied by 72.5 gives the percentage of magnesia. The precipitate so obtained always contains some calcium and usually small quantities of iron, aluminum, and manganese as phosphates.

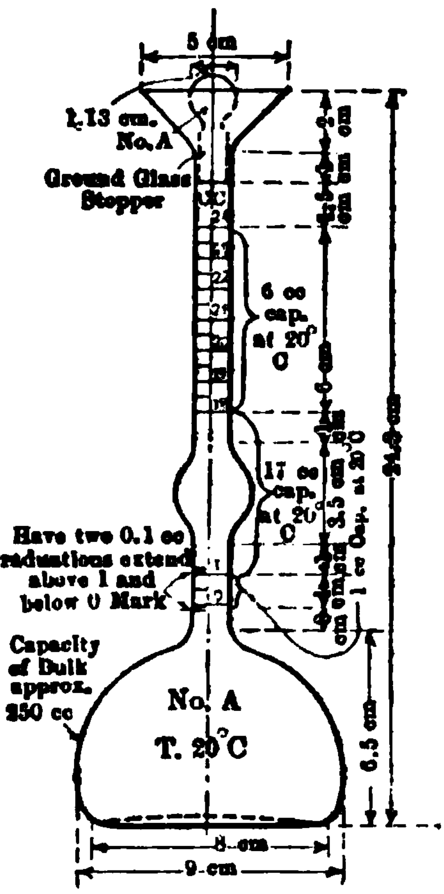

Fig. 40

"27. Permissible Variation. A permissible variation of 0.4 will be allowed, and all results in excess of the specified limit but within this permissible variation shall be reported as 5%.

"28. Determination of Specific Gravity. Apparatus. The determination of specific gravity shall be made with a standardized Le Chatelier apparatus which conforms to the requirements illustrated in Fig. 40. This apparatus is standardized by the U. S. Bureau of Standards. Kerosene free from water, or benzine not lighter than 62° B, shall be used in making this determination.

"29. Method. The flask shall be filled with either of these liquids to a point on the stem between zero and one cubic centimeter, and 64 g of cement, of the same temperature as the liquid, shall be slowly introduced, taking care that the cement does not adhere to the inside of the flask above the liquid and to free the cement from air by rolling the flask in an inclined position. After all the cement is introduced, the level of the liquid will rise to some division of the graduated neck; the difference between readings is the volume displaced by 64 g of the cement.

$$\text{SPECIFIC GRAVITY} = \frac{\text{WEIGHT OF CEMENT, g}}{\text{DISPLACED VOLUME, cc}}$$

"30. The flask, during the operation, shall be kept immersed in water in order to avoid variations in the temperature of the liquid in the flask, which shall not exceed 0°.5 C (0°.9 F). The results of repeated tests should agree within 0.01.

"31. The determination of specific gravity shall be made on the cement as received; if it falls below 3.10, a second determination shall be made after igniting the sample as described in (Par. 20)

"32. Determination of Fineness. Apparatus. Wire cloth for standard sieves for cement shall be woven, not twilled, from brass, bronze, or other suitable wire, and mounted without distortion on frames not less than 1½ in below the top of the frame. The sieve frames shall be circular, approximately 8 in in diameter, and may be provided with a pan and cover.

"33. A standard 200-mesh sieve is one having nominally an 0.0029-in opening and 200 wires per in standardized by the U. S. Bureau of Standards, and conforming to the following requirements: The 200-mesh sieve should have 200 wires per in, and the number of wires in any whole inch shall not be outside the limits of 192 to 208. No opening between adjacent parallel wires shall be more than 0.0050 in in width. The diameter of the wire should be 0.0021 in and the average diameter shall not be outside the limits 0.0019 to 0.0023 in. The value of the sieve as determined by sieving tests made in conformity with the standard specification for these tests on a standardized cement which gives a residue of 20 to 25% on the 200-mesh sieve, or on other similarly graded material, shall not show a variation of more than 1.5% above or below the standards maintained at the Bureau of Standards.

"34. METHOD. The test shall be made with 50 g of cement. The sieve shall be thoroly clean and dry. The cement shall be placed on the 200-mesh sieve, with pan and cover attached, if desired, and shall be held in one hand in a slightly inclined position so that the sample will be well distributed over the sieve, at the same time gently striking the side about 150 times per min against the palm of the other hand on the upstroke. The sieve shall be turned every 25 strokes about ⅙ of a revolution in the same direction. The operation shall continue until not more than 0.05 g passes thru in 1 min of continuous sieving. The fineness shall be determined from the weight of the residue on the sieve expressed as a percentage of the weight of the original sample.

"35. Mechanical sieving devices may be used, but the cement shall not be rejected if it meets the fineness requirement when tested by the hand method.

"36. A PERMISSIBLE VARIATION of 1 will be allowed, and all results in excess of the specified limit but within this permissible variation shall be reported as 22%.

"37. Mixing Cement Pastes and Mortars. METHOD. The quantity of dry material to be mixed at one time shall not exceed 1000 g nor be less than 500 g. The proportions of cement or cement and sand shall be stated by weight in grams of the dry materials; the quantity of water shall be expressed in cubic centimeters, 1 g = 1 cc. The dry materials shall be weighed, placed upon a non-absorbent surface, thoroly mixed dry if sand is used, and a crater formed in the center, into which the proper percentage of clean water shall be poured; the material on the outer edge shall be turned into the crater by the aid of a trowel. After an interval of ½ min for the absorption of the water the operation shall be completed by continuous, vigorous mixing, squeezing and kneading with the hands for at least 1 min.* During the operation of mixing, the hands should be protected by rubber gloves.

"38. The temperature of the room and the mixing water shall be maintained as nearly as practicable at 21° C (70° F).

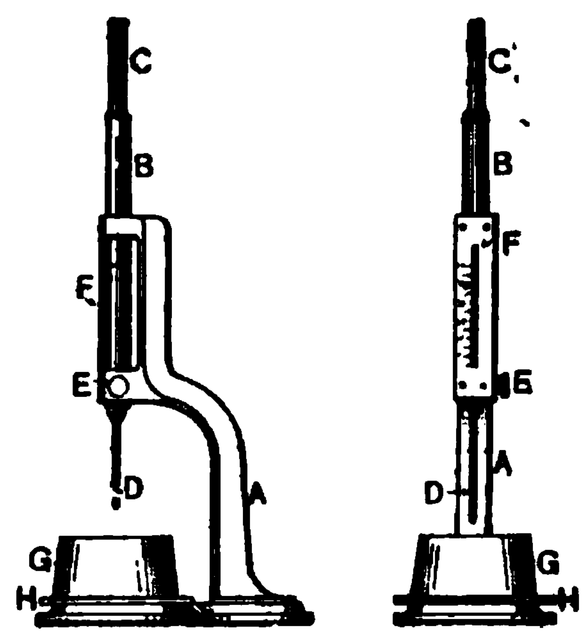

Fig. 41.

"39. Normal Consistency. APPARATUS. The Vicat apparatus consists of a frame *A* (Fig. 41) bearing a movable rod *B*, weighing 300 g, one end *C* being 1 cm in diameter for a distance of 6 cm, the other having a removable needle *D*, 1 mm in diameter, 6 cm long. The rod is reversible, and can be held in any desired position by a screw *E*, and has midway between the ends a mark *F* which moves under a scale, graduated to millimeters, attached to the frame *A*. The paste is held in a conical, hard-rubber ring *G*, 7 cm in diameter at the base. 4 cm high, resting on a glass plate *H* about 10 cm square.

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*In order to secure uniformity in the results of tests for the time of setting and tensile strength the manner of mixing above described should be carefully followed. At least 1 min is necessary to obtain the desired plasticity which is not appreciably affected by continuing the mixing for several minutes. The exact time necessary is dependent upon the personal equation of the operator. The error in mixing should be on the side of over mixing.

"40. Method. In making the determination, 500 g of cement, with a measured quantity of water, shall be kneaded into a paste, as described in (Par. 37), and quickly formed into a ball with the hands, completing the operation by tossing it six times from one hand to the other, maintained about 6 in apart; the ball resting in the palm of one hand shall be pressed into the larger end of the rubber ring held in the other hand, completely filling the ring with paste; the excess at the larger end shall then be removed by a single movement of the palm of the hand; the ring shall then be placed on its larger end on a glass plate and the excess paste at the smaller end is sliced off at the top of the ring by a single oblique stroke of a trowel held at a slight angle with the top of the ring. During these operations care shall be taken not to compress the paste. The paste confined in the ring, resting on the plate, shall be placed under the rod, the larger end of which shall be brought in contact with the surface of the paste; the scale shall be then read, and the rod quickly released. The paste shall be of normal consistency when the rod settles to a point 10 mm below the original surface in ½ min after being released. The apparatus shall be free from all vibrations during the test. Trial pastes shall be made with varying percentages of water until the normal consistency is obtained. The amount of water required shall be expressed in percentage by weight of the dry cement.

"41. The consistency of standard mortar shall depend on the amount of water required to produce a paste of normal consistency from the same sample of cement. Having determined the normal consistency of the sample, the consistency of standard mortar made from the same sample shall be as indicated in Table IV, the values being in percentage of the combined dry weights of the cement and standard sand.

Table IV.—Percentage of Water for Standard Mortars

Percentage of Water for Neat Cement Paste of Normal Consistency	Percentage of Water for One Cement, Three Standard Ottawa Sand	Percentage of Water for Neat Cement Paste of Normal Consistency	Percentage of Water for One Cement, Three Standard Ottawa Sand
15	9.0	23	10.3
16	9.2	24	10.5
17	9.3	25	10.7
18	9.5	26	10.8
19	9.7	27	11.0
20	9.8	28	11.2
21	10.0	29	11.3
22	10.2	30	11.5

"42. Determination of Soundness.* Apparatus. A steam apparatus, which can be maintained at a temperature between 98° and 100° C (208° and 212° F), or one similar to that shown in Fig. 42, is recommended. The capacity of this apparatus may be increased by using a rack for holding the pats in a vertical or inclined position.

"43. Method. A pat from cement paste of normal consistency about 3 in in diameter, ½ in thick at the center, and tapering to a thin edge, shall be made on clean glass plates about 4 in square, and stored in moist air for 24 hr. In molding the pat, the cement paste shall first be flattened on the glass and the pat then formed by drawing the trowel from the outer edge toward the center.

"44. The pat shall then be placed in an atmosphere of steam at a temperature between 98° and 100° C (208° and 212° F), upon a suitable support 1 in above boiling water for 5 hr.

"45. Should the pat leave the plate, distortion may be detected best with a straight edge applied to the surface which was in contact with the plate.

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*Unsoundness is usually manifested by change in volume which causes distortion, cracking, checking or disintegration. Pats improperly made or exposed to drying may develop what are known as shrinkage cracks within the first 24 hr and are not an indication of unsoundness. The failure of the pats to remain on the glass or the cracking of the glass to which the pats are attached does not necessarily indicate unsoundness.

"46. **Determination of Time of Setting.** The following are alternate methods, either of which may be used as ordered:

"47. Vicat Apparatus. The time of setting shall be determined with the Vicat apparatus described in (Par. 39). See Fig. 41.

"48. Vicat Method. A paste of normal consistency shall be molded in the hard-rubber ring G as described in (Par. 40) and placed under the rod B, the smaller end of

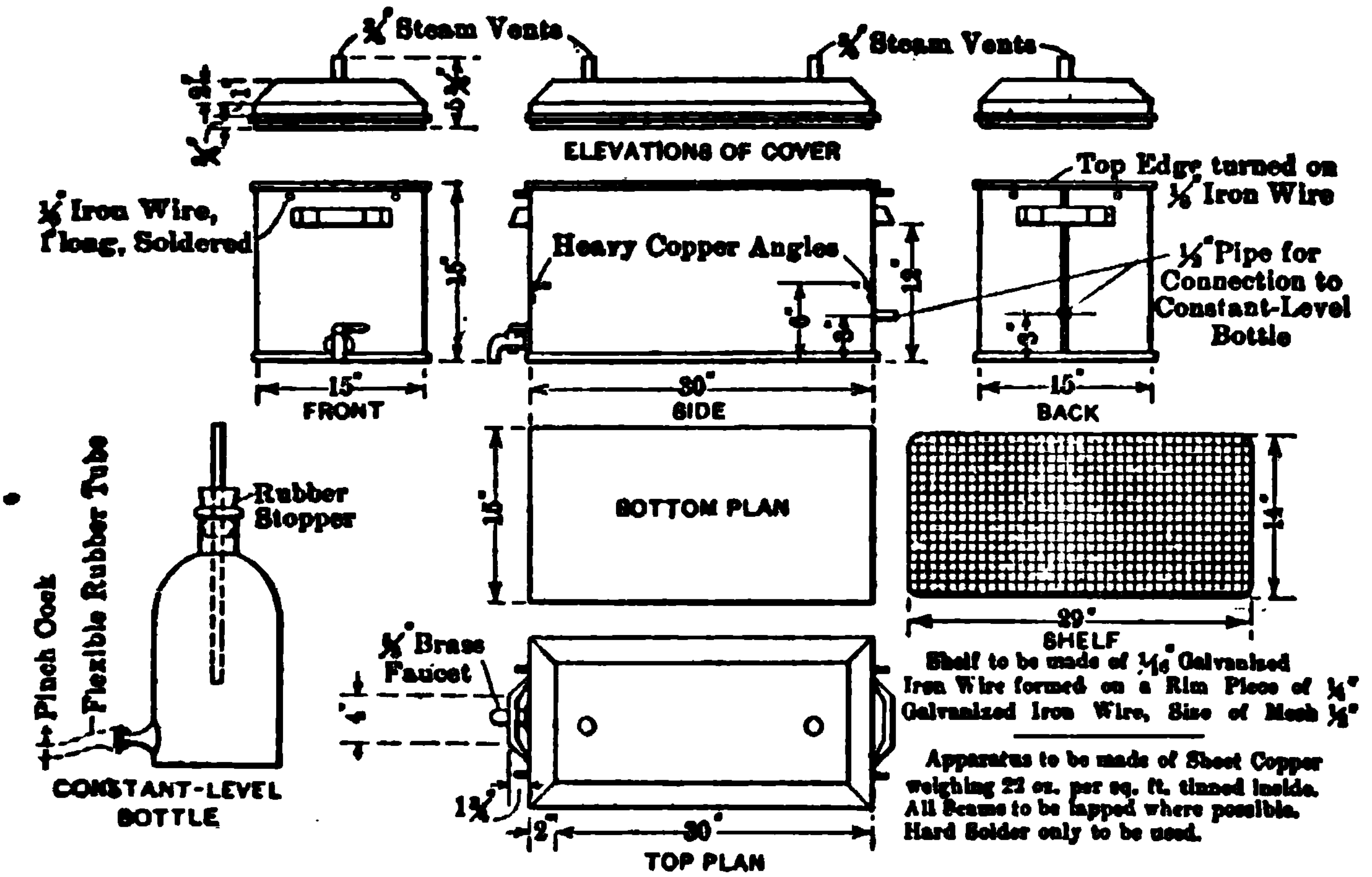
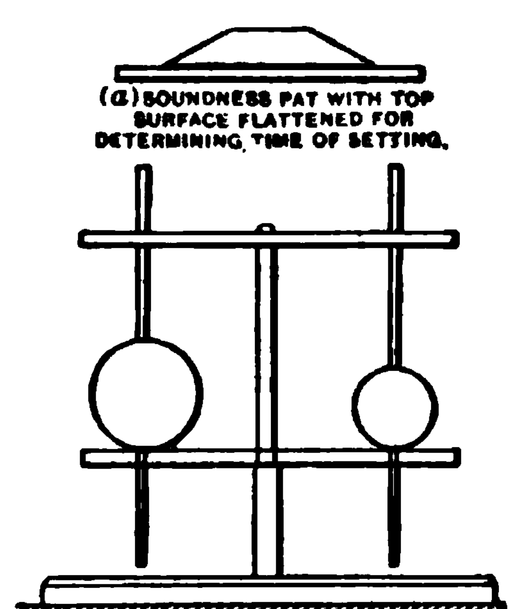


Fig. 42

which shall then be carefully brought in contact with the surface of the paste, and the rod quickly released. The initial set shall be said to have occurred when the needle ceases to pass a point 5 mm above the glass plate in ½ min after being released; and the final set, when the needle does not sink visibly into the paste. The test pieces shall be kept in moist air during the test. This may be accomplished by placing them on a rack over water contained in a pan and covered by a damp cloth, kept from contact with them by means of a wire screen; or they may be stored in a moist closet. Care shall be taken to keep the needle clean, as the collection of cement on the sides of the needle retards the penetration, while cement on the point may increase the penetration. The time of setting is affected not only by the percentage and temperature of the water used and the amount of kneading the paste receives, but by the temperature and humidity of the air, and its determination is therefore only approximate.



(a) SOUNDNESS PAT WITH TOP SURFACE FLATTENED FOR DETERMINING TIME OF SETTING.

(b) GILLMORE NEEDLES.

Fig. 43

"49. Gillmore Apparatus. The time of setting shall be determined by the Gillmore needles. The Gillmore needles should preferably be mounted as shown in Fig. 43 (*b*).

"50. Gillmore Method. The time of setting shall be determined as follows: A pat of neat cement paste about 3 in in diameter and ½ in in thickness with a flat top, see Fig. 43 (*a*), mixed to a normal consistency, shall be kept in moist air at a temperature maintained as nearly as practicable at 21° C (70° F). The cement shall be considered to have acquired its initial set when the pat will bear, without appreciable indentation, the Gillmore needle 1/12 in in

diameter, loaded to weigh ¼ lb. The final set has been acquired when the pat will bear without appreciable indentation, the Gillmore needle 1/24 in in diameter, loaded to weigh 1 lb. In making the test, the needles shall be held in a vertical position, and applied lightly to the surface of the pat.

"51. Tension Tests. Form of Test Piece. The form of test piece shown in Fig. 44 shall be used. The molds shall be made of non-corroding metal and have sufficient material in the sides to prevent spreading during molding. Gang molds when used shall be of the type shown in Fig. 45. Molds shall be wiped with an oily cloth before using.

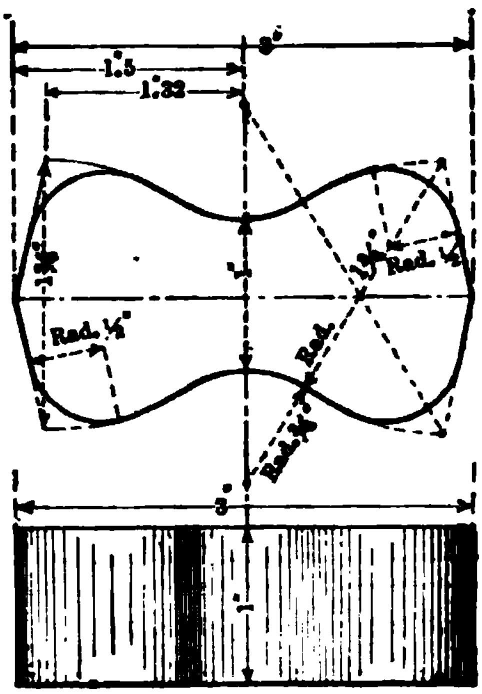


Fig. 44

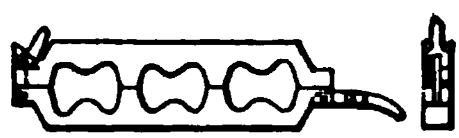


Fig. 45

"52. Standard Sand. The sand to be used shall be natural sand from Ottawa, Ill., screened to pass a 20-mesh sieve and retained on a 30-mesh sieve. This sand may be obtained from the Ottawa Silica Co., at a cost of 2 cents per lb, f.o.b. cars, Ottawa, Ill.

"53. This sand having passed the 20-mesh sieve shall be considered standard when not more than 5 g pass the 30-mesh sieve after 1 min continuous sieving of a 500-g sample.

"54. The sieves shall conform to the following specifications:

"The 20-mesh sieve shall have between 19.5 and 20.5 wires per whole inch of the warp wires and between 19 and 21 wires per whole inch of the shoot wires. The diameter of the wire should be 0.0165 in and the average diameter shall not be outside the limits of 0.0160 and 0.0170 in.

"The 30-mesh sieve shall have between 29.5 and 30.5 wires per whole inch of the warp wires and between 28.5 and 31.5 wires per whole inch of the shoot wires. The diameter of the wire should be 0.0110 in and the average diameter shall not be outside the limits 0.0105 to 0.0115 in.

"55. Molding. Immediately after mixing, the standard mortar shall be placed in the molds, pressed in firmly with the thumbs and smoothed off with a trowel without ramming. Additional mortar shall be heaped above the mold and smoothed off with a trowel; the trowel shall be drawn over the mold in such a manner as to exert a moderate pressure on the material. The mold shall then be turned over and the operation of heaping, thumbing and smoothing off repeated.

"56. Testing. Tests shall be made with any standard machine. The briquettes shall be tested as soon as they are removed from the water. The bearing surfaces of the clips and briquettes shall be free from grains of sand or dirt. The briquettes shall be carefully centered and the load applied continuously at the rate of 600 lb per min.

"57. Testing machines should be frequently calibrated in order to determine their accuracy.

"58. Briquettes that are manifestly faulty, or which give strengths differing more than 15% from the average value of all test pieces broken at the same period and made from the same sample, shall not be considered in determining the tensile strength.

"59. Storage of Test Pieces. Apparatus. The moist closet should consist of a soapstone, slate or concrete box, or a wooden box lined with metal. If a wooden box is used, the interior should be covered with felt or broad wicking kept wet. The bottom of the moist closet should be covered with water. The interior of the closet should be provided with non-absorbent shelves on which to place the test pieces, the shelves being so arranged that they may be withdrawn readily.

"60. Methods. Unless otherwise specified all test pieces, immediately after molding, shall be placed in the moist closet for from 20 to 24 hr.

"61. The briquettes shall be kept in molds on glass plates in the moist closet for at least 20 hr. After 24 hr in moist air the briquettes shall be immersed in clean water in storage tanks of non-corroding material.

"62. The air and water shall be maintained as nearly as practicable at 21° C (70° F)."

Am. Soc. Test. Mat. Standard Specifications for Natural Cement as revised in 1909 (63 m).

"1. **Definition.** Natural cement is the finely pulverized product resulting from the calcination of an argillaceous limestone at a temperature only sufficient to drive off the carbonic acid gas.

"2. **Physical Properties.** FINENESS. The residue on a standard 100-mesh sieve shall not exceed 10%, and on a standard 200-mesh sieve shall not exceed 30%, by weight.

"3. SOUNDNESS. Pats of neat cement about 3 in in diameter, ½ in thick at center, tapering to a thin edge, shall be kept in moist air for a period of 24 hr.

a. A pat shall then be kept in air at normal temperature.

b. Another pat shall be kept in water maintained as near 21° C (70° F) as practicable. These pats shall be observed at intervals for at least 28 days, and, to satisfactorily pass the tests, shall remain firm and hard and show no signs of distortion, checking, cracking or disintegrating.

"4. TIME OF SETTING. The cement shall not develop initial set in less than 10 min, using the Vicat needle. Final set shall be attained in not less than 30 min nor more than 3 hr, using the Vicat needle.

"5. TENSILE STRENGTH. The minimum requirements for tensile strength for briquettes 1 sq in in cross-section shall be as follows, and the cement shall show no retrogression in strength within the periods specified:

Age	Strength
Neat Cement	
24 hr in moist air	75 lb
7 days, 1 day in moist air, 6 days in water	150 lb
28 days, 1 day in moist air, 27 days in water	250 lb
One Part Cement, Three Parts Standard Ottawa Sand	
7 days, 1 day in moist air, 6 days in water	50 lb
28 days, 1 day in moist air, 27 days in water	125 lb

"6. **Packages, Marking and Storage.** The cement shall be delivered in suitable bags or barrels with the brand and name of the manufacturer plainly marked thereon. A bag shall contain 94 lb net. A barrel shall contain 282 lb net.

"7. The cement shall be stored in such a manner as to permit easy access for proper inspection and identification of each shipment, and in a suitable weather-tight building which will protect the cement from dampness.

"8. **Inspection.** a. Every facility shall be provided the purchaser for careful sampling and inspection at either the mill or at the site of the work, as may be specified by the purchaser. At least 10 days from the time of sampling shall be allowed for the completion of the 7-day test, and at least 31 days shall be allowed for the completion of the 28-day test.

b. The cement shall be tested in accordance with the methods contained in the Standard Specifications and Tests for Portland Cement of the Am. Soc. Test. Mat.

"9. **Rejection.** The cement may be rejected if it fails to meet any of the requirements of these specifications.

"10. Cement failing to meet the 7-day requirements may be held awaiting the results of the 28-day tests before rejection."

13. Plain Cement-Concrete

Too little attention has been given to the materials to be cemented together to make concrete. Concrete failures have been attributed to poor cement. While poor cement may be found in the market, there is no other material of construction which is as thoroly tested by the manufacturers. As a matter of fact, good cement saves poor aggregate more often than it causes failure. Therefore, it is a sound proposition that sand, gravel and stone must be tested. Tests have been made in the past for sharpness in sand. While a sharp sand may give concrete that is a little stronger than that made from round particles, it is not as dense and therefore not so nearly waterproof. As a general proposition, one offsets the

other. Tests have been made for cleanness of sand. But it is conceded that 5 or even 10% of good clay is not injurious to the sand as used for concrete. Aggregates for concrete are usually divided into fine and coarse, the division usually being made by the point of what will pass and what will be retained upon a ¼-in screen. The N. Y. State Highway Comm. standard specifications make the ⅜-in screen the dividing line.

Fine Aggregate may consist of sand, gravel screenings, crushed stone or crushed slag. The best is that which is made up entirely of siliceous materials. It should be made up of all sizes of grains from fine, hard particles up to ¼ in. The Committee on Concrete, Am. Soc. C. E., reported in 1914 that not more than 6% should pass a 100-mesh sieve. It should be free from dust, and particularly it must be free from vegetable loam and all other organic matter. A fine aggregate may look all right and still be entirely unfit for use in concrete. It therefore should be tested by making standard briquettes from a 1 : 3 mortar and comparing the results with a 1 : 3 mortar made from the same cement and standard Ottawa sand. In making such a test, the consistency of the two mortars should be about the same. In order to obtain the same consistency the natural sand mortar will require from 10 to 40% more water than the Ottawa sand. A natural sand failing to come up to this requirement might be used by increasing the proportion of cement. If the test gives results less than 70% of the value of the Ottawa sand briquettes, the material should be rejected.

Coarse Aggregate should consist of crushed rock, slag or gravel which will be retained on a ¼-in screen. All that was said under fine aggregate regarding freedom from dust, vegetable loam and organic matter is applicable to the coarse aggregate. The particles should be hard and should be cubical or spherical in shape. Long or flat stones should be rejected. They are liable not to mix well, or may break after mixing and leave exposed areas not coated with mortar. The maximum size of coarse aggregate is dependent upon the character of the work. For plain concrete in thin masses, from 6 in to 12 in thick, stone up to 1½ or even 2 in may be used. In larger masses of plain concrete stone up to 2½ or 3 in may be used. A limited amount of these large stones tends to increase the strength of the concrete, but makes it more difficult to properly mix and place it, as they have a tendency to separate from the mortar. The aggregate should be so graded between the minimum and maximum sizes, that it is made up of nearly equal amounts of all the different sizes.

Proportioning. Inasmuch as a bag of Portland cement measures about 1 cu ft and weighs 94 lb, 1 cu ft of loose dry sand weighs about 95 lb and 1 cu ft of loose coarse aggregate weighs less than 100 lb; the common unit of measuring proportions is taken as the cubic foot of loose aggregate or the bag of cement. The proportioning of fine aggregate to coarse aggregate should be such as to produce a mixture having a minimum of voids. In unimportant work, this may be closely enough obtained by taking twice as much coarse aggregate as fine. For important work, a careful study should be made to obtain the very best results, and the proper mixture should be carefully maintained thruout the work. See (54).

Proportion. For plain concrete in large masses, such as foundations, it is common to make it in the proportion 1 : 2½ : 5, which means one bag of Portland cement, to 2½ cu ft of fine aggregate and 5 cu ft of coarse aggregate. If all the aggregate is carefully graded, a concrete in the proportion of 1 : 3 : 6 may be used. For reinforced concrete and for plain concrete in small, thin masses, the proportion should be 1 : 2 : 4.

A considerable number of states specify a proportion of 1 : 1½ : 3 for concrete pavement construction; but a large number of highway engineers claim that a 1 : 2 : 4 mixture is at least as good, see Sect. 21. Having decided upon the proportion to be used, an estimate of the quantities necessary for a cubic yard of concrete may be obtained from the following formulas, devised by Wm. B. Fuller (54). $C = \frac{11}{c+s+g}$; $S = C \times s \times \frac{3.8}{27}$; $G = C \times g \times \frac{3.8}{27}$; in which C = number of barrels of packed Portland cement required for 1 cu yd of concrete, 1 bbl = 4 bags, S = number of cubic yards of loose sand required for 1 cu yd of concrete, G = number of cubic yards of loose gravel or broken stone required for 1 cu yd of concrete, c = number of parts of cement in proportion, s = number of parts of sand in proportion, g = number of parts of gravel, etc, in proportion.

Water for concrete is seldom tested. But care should be used that the water is not alkaline, and that it contains no oils. The amount of water will vary according to plasticity wanted. For plain concrete, it may be estimated that 1 cu ft of concrete will take from 1 to 1¼ gal of water. Reinforced concrete will require at least 1¼ gal to a cu ft.

Mixing Concrete should be done carefully and thoroly. Proper mixing should coat every particle of fine aggregate with cement and every piece of coarse aggregate with mortar. It should bring the pieces of coarse aggregate into intimate contact with the mortar so that the mortar will closely adhere to them. The time allowed for mixing should be sufficient to accomplish these results, but should not be so long as to run any risk of the cement beginning to set before it is placed in the forms and rammed. Concrete is mixed by hand and by machine. As a rough estimate, on a work requiring 200 cu yd or more of concrete, machine mixing may be economy. With a good machine, better concrete is always obtained.

If Mixed by Hand, it is done in two-bag batches. A bottomless box of such inside dimensions that when even full it will contain the proper amount of sand to mix with one bag of cement is placed on the mixing board, filled even full with sand. The box is then removed and the sand spread out. Two bags of cement are then dumped on the sand. Then the box is again filled and the contained sand is shoveled on top of the cement. Then the cement and sand are mixed by shovels. The shovelful should not be merely dumped, but the material should be allowed to run off of the shovel in such manner as to mix the two materials. A proper mix is obtained when the color of the mixture runs even. By a similar process, measure half the stone required. Spread the dry mortar on top, then spread the remainder of stone. Add water and turn the entire mass over at least 4, and better, 6 times.

Machine Mixers. There is a large number of machine mixers on the market. Continuous mixers are either horizontal or vertical. In the latter the various materials in their proper proportions, including water, are continuously shovelled into the top. They drop on to sloping shelves, and by being dropped from shelf to shelf become mixed before coming out at the bottom. Most continuous mixers are nearly horizontal cylinders. The materials are shovelled in at one end and the passage thru is either by a large revolving screw which carries the material along, or by the revolving of the cylinder. Batch mixers are so called because all the materials for 1 batch, based on 1 bag of cement, are placed in the mixer and are allowed to revolve inside of it for about 2 min when the batch is dumped out. For machine mixing, the proportions are usually measured by actually measuring for 1 batch and noting how full 1 or 2 wheelbarrows are made by the measured quantities. All measuring after that is made by filling wheelbarrows to proper extent.

Transporting and Placing. The concrete may be carried from the mixer to the site of the work by means of wheelbarrows, or on larger jobs by two-wheeled barrows which are so constructed as to be easily operated by one man, altho a large size is made that in some cases is best handled by 2 men. Generally, the first concrete should be placed farthest from the

mixer, gradually working back towards the mixer, so avoiding having to pass thru the placed concrete. If concrete is being dumped into wall forms from a runway, this precaution is not necessary. But the runway should make a complete circuit so that the barrow leaves the mixer dumps at the proper place and continues around the circuit back to the mixer, not interfering with the other barrows. If the concrete is dry, it should not be dropped from any height. But ordinary wet concrete may, with care, be dropped into place from heights of 10 or 12 ft. Under no conditions, however, should concrete be placed by dropping thru any depth of water. A depth of even 3 or 4 ft will separate the materials from which the concrete is made, the clear stone going to the bottom, while the fine aggregate and cement will form layers above it. Concrete may be placed under water by filling paper bags with it and sliding them into place by means of a chute. The bags will soon burst and the concrete forms a fairly solid mass. The best method is usually to chute the concrete thru a 12- or 14- in diameter tube, either wooden or steel. The bottom end of the tube may be closed by a slide operated from the upper end, or the first batch of concrete may be permitted to fall thru the water. After that, the plastic concrete keeps the lower end of the tube sealed.

Foundation Concrete should be placed in layers 6 or 8 in thick. Dry concrete needs a rammer weighing at least 20 lb. But wet concrete may be rammed by means of 2 by 4 in scantling rounded off for a handle on one end. Men who use these should be supplied with rubber boots and allowed to walk in the concrete. This adds to the ramming. Care should be used not to continue ramming after the cement has begun to set. The concrete should then be protected from the sun to prevent drying out and should not be walked on for from 1 to 5 days. An ideal method in placing concrete is to work continuously until the entire mass is placed. This is usually impracticable, and then care must be used in beginning each day's work, or even every half day's work, to get a bond between the old concrete and the new. The concrete already set should be clean and free from loose particles before new concrete is placed on or against it. It should be somewhat rough and should be washed before placing the new concrete. But water should not be left standing on it. The first batch of new concrete should be without coarse aggregate, thus forming a mortar joint, into which the following batches of concrete are placed. Any oil in the water or from the forms may form a film on the set concrete that must be removed before the new concrete is placed, or there will be practically no bond between the two. If there is any possibility of any stress other than pure compression ever coming onto the concrete, it is always wise to have a mechanical bond between old and new concrete. The most simple method is to ram 2 by 4 in scantling into the last batch of concrete at night. This may be removed in the morning and the new concrete forms a tongue in the groove left by the removal of the scantling, thus forming a regular joint to resist transverse stresses. Features to be kept in mind in the building of forms may be found in Sect. 26, RETAINING WALLS.

Imperviousness is a quality which is frequently of great importance in concrete. Retaining walls, foundations and other structures which come into intimate contact with soil should be so constructed that water will not seep thru. The simplest method of accomplishing this is by increasing the amount of cement in the mixture. Cement is more porous than concrete. But its voids are made up of minute round bubbles which are without intercommunication. The voids in concrete are thin and hair-

like in construction, and cross and re-cross each other in all directions. Therefore the increase of cement may increase percentage of voids, but at same time increases water-proofing. The concrete surface may be water-proofed against small pressures by thoroly troweling the surface which tends to bring the cement to the surface thereby acting as a water-proof coating. It should be remembered that gravel will generally make a denser and therefore a more nearly water-proof concrete than will crushed rock. Lean mixtures of concrete may be made more water-proof by the addition of 12 to 15% of slaked lime, or not more than 10% of fine clay. These materials tend to fill the voids and are therefore nearly useless in a rich concrete. The oldest and probably the best water-proofing materials are alum and soap used in combination. Soap to the amount of 3% of the water should be dissolved in the water. Finely powdered alum equal to half the amount of soap used may be either dissolved in the water or mixed dry with the cement. This mixing of the soap and alum directly with the ingredients decreases the strength of the concrete slightly. If necessary to avoid this, or if water-proofing is desired on a structure already built, the alum and soap should be used as washes over the exposed surface. It is always better, if possible, to place these washes on the surface actually exposed to the water pressure. The alum solution is made by using 1 lb of alum to 1 gal of water. The soap solution by using 2.2 lb of hard soap to 1 gal of water. These washes are applied separately, either the alum or soap wash being allowed to dry 24 hr before the application of the other. The soap wash should be boiling hot, the alum wash should be about 15.6° to 21°C (60° or 70° F). The concrete should not be colder than 10° C (50° F). These two washes combine to form an insoluble compound, and several coatings will water-proof concrete against heavy water pressures.

Concrete in Freezing Weather. It is always advisable not to do concrete work in freezing weather. But with extra care, it may be done with perfect safety. In the first place, the chemical action of setting cement creates a considerable amount of heat. By covering the day's work with cement bags, burlap, straw, etc, this heat is held in the concrete until it sets. With ordinary care this method will prevent freezing at − 4° C (25° F) and with great care, at − 7° C (20° F). The surest method to prevent freezing at lower temperatures is to add, to the water, salt to the amount of 0.2% of the weight of water for every 0.44° C (1° F) below freezing, that the temperature may fall. This may cause efflorescence on the face of the concrete, but that will soon disappear. When the work is large enough to keep up steam on the job for 24 hr a day and 7 days a week, freezing may be largely prevented by piping live steam thru the piles of sand and stone. But the effect of steam on cold stone is merely to warm the surface. The frost in the interior is liable to come out after the concrete is in place. This lowers the temperature of concrete and is liable to cause trouble.

14. Reinforced Cement-Concrete

A brief outline of the principles governing the use and design of reinforced cement-concrete will be given. The material in this article is taken from the 1913 and 1917 reports of the Com. on Concrete and Reinforced Concrete, Am. Soc. C. E. (62 b). The use of reinforced concrete involves the exercise of good judgment to a greater degree than for any other building material, and judgment should control the application of rules. Failures of such structures are usually due to any one or a combination of the following causes: Defective design, poor material, faulty

execution and premature removal of forms. Poor material is sometimes used for the concrete, as well as for the reinforcement. The use of poor aggregates, especially sand, which have not been tested is a common source of defect. An unsuitable quality of metal for reinforcement is sometimes used to reduce the cost.

The Materials may be divided into (1) cement, (2) aggregates, and (3) reinforcement. Only Portland cement should be used and it should pass the tests as prescribed under Art. 12. Aggregates may be divided into (a) fine and (b) coarse. Fine aggregates should consist of sand, crushed stone, or gravel screenings, graded from fine to coarse, and passing, when dry, a ¼-in screen. It should be clean, coarse, free from dust, soft particles, vegetable loam or other deleterious matter; and not more than 6% should pass a 100-mesh sieve. Coarse aggregate should consist of crushed stone or gravel which is retained on a ¼-in screen and graded from the smallest to the largest particles. It should be clean, hard, durable and free from all deleterious matter. The maximum size of the particles is governed by the character of the construction and should be small enough to allow the concrete to easily surround the reinforcement and fill all parts of the forms. Cinder concrete should not be used for reinforced concrete construction. For reinforcement, a structural steel with an ultimate tensile strength of 60 000 lb per sq in and a yield point of not less than 60% of the ultimate strength should be used. Where little bending is required, and also for reinforcement for shrinkage and temperature stresses, a high carbon steel with an ultimate strength of 88 000 lb per sq in and a yield point of not less than 60% of the ultimate strength may be used.

In Proportioning the Concrete, the fine and coarse aggregates should be used in such relative proportions as will insure maximum density. A study of samples of the aggregate should be made to determine this relation. In ordinary construction, 1 part of cement to a total of 6 parts of fine and coarse aggregates measured separately should generally be used. For columns, richer mixtures are generally preferable, and in massive masonry, a mixture of 1:9 or even 1:12 may be used.

Shrinkage of Concrete due to hardening, and contraction due to temperature changes, causes cracks, the size of which depends on the extent of the mass. The resulting stresses are important in monolithic construction and should be considered carefully by the designer. They cannot be counteracted successfully but the effects can be minimized. In long continuous lengths of concrete, shrinkage joints should be provided at points where they will do little or no harm. Reinforcement, properly placed, is of assistance in causing the concrete to hold together between joints and to localize the cracks.

Continuous Beams and Slabs. In computing the positive and negative moments in beams and slabs continuous over several supports, due to uniformly distributed loads, the following rules are given:

1. That for floor slabs, the bending moments at center and at support be taken at $wL^2/12$ for both dead and live loads, where w represents the load per linear foot and L the span length.

2. That for beams, the bending moment at center and at support for interior spans be taken at $wL^2/12$, and for end spans it be taken at $wL^2/10$ for center and adjoining support, for both dead and live loads.

3. In the case of beams and slabs continuous for two spans only, the bending moment at the central support should be taken as $wL^2/8$ and near the middle of the span as $wL^2/10$.

4. At the ends of continuous beams, the amount of negative moment which will

be developed will depend on the condition of restraint or fixedness, and this will depend on the form of construction. In ordinary cases a moment of from $wL^2/16$ to $wL^2/12$ may be used.

Columns. By columns are meant compression members of which the ratio of unsupported length to least width exceeds about 4, and which are provided with reinforcement. It is recommended that the ratio of unsupported length of column to its least width be limited to 15. The effective area of the column shall be taken as the area within the protective covering, or, in the case of hooped columns or columns reinforced with structural shapes, it shall be taken as the area within the hooping or structural shapes. The following recommendations are made for the relative working stresses in the concrete for the several types of columns:

1. Columns with longitudinal reinforcement to the extent of not less than 1 and not more than 4%, and with lateral ties of not less than ¼ in in diameter, 12 in apart, nor more than 16 diameters of the longitudinal bar: the unit stress recommended for axial compression.

2. Columns reinforced with not less than 1 and not more than 4% of longitudinal bars, and with circular hoops or spirals not less than 1% of the volume of the concrete: a unit stress 55% higher than given for (1) provided the ratio of unsupported length of column to diameter of the hooped core is not more than 10.

Working Stresses. The following working stresses are given for static loads. Proper allowances for vibration and impact are to be added to live loads where necessary to produce an equivalent static load before applying the unit stresses in proportioning parts.

Table V.—Strengths of Different Mixtures of Concrete

In Pounds per Square Inch

Aggregate	1 : 3*	1 : 4½*	1 : 6*	1 : 7½*	1 : 9*
Granite, trap rock	3300	2800	2200	1800	1400
Gravel, hard limestone and hard sandstone	3000	2500	2000	1600	1300
Soft limestone and sandstone	2200	1800	1500	1200	1000
Cinders	800	700	600	500	400

*Combined volume fine and coarse aggregate measured separately.

Bearing. When compression is applied to a surface of concrete of at least twice the loaded area, a stress of 35% of the compressive strength may be allowed.

Axial Compression. For concentric compression on a plain concrete pier, the length of which does not exceed 4 diameters, or on a column reinforced with longitudinal bars only, the length of which does not exceed 12 diameters, 22.5% of the compressive strength may be allowed.

Compression in Extreme Fiber. The extreme fiber stress of a beam, calculated on the assumption of a constant modulus of elasticity for concrete under working stresses may be allowed to reach 32.5% of the compressive strength. Adjacent to the support of continuous beams, stresses 15% higher may be used.

Shear and Diagonal Tension. In calculations on beams in which the maximum shearing stress in a section is used as the means of measuring the resistance to diagonal tension stress, the following allowable values are recommended: (1) For beams with horizontal bars only and without web reinforcement, 2% of the compressive strength. (2) For a combination of bent bars and vertical stirrups looped about the reinforcing bars in the tension side of the beam and spaced horizontally not more than one-half of the depth of the beam, 5% of the compressive strength. For other cases of web reinforcement consisting of vertical stirrups or bent bars or a combination thereof, see (62 b).

Bond. The bond stress between concrete and plain reinforcing bars may be assumed at 4% of the compressive strength or 2% in the case of drawn wire.

Reinforcement. The tensile or compressive strength in steel should not exceed 16 000 lb per sq in.

Modulus of Elasticity. The value of the modulus of elasticity of concrete has a wide range, depending on the materials used, the age, the range of stresses between which it is considered, as well as other conditions. It is recommended that in computations for the position of the neutral axis and for the resisting moment of beams and for the compression of concrete in columns it be assumed as: (1) One-fortieth that of steel, when the strength of concrete is taken as not more than 800 lb per sq in. (2) One-fifteenth of that of steel, when the strength of the concrete is taken as greater than 800 lb per sq in and less than 2200 lb per sq in. (3) One-twelfth of that of steel, when the strength of the concrete is taken as greater than 2200 lb per sq in and less than 2900 lb per sq in. (4) One-tenth of that of steel, when the strength of the concrete is taken as greater than 2900 lb per sq in.

Formulas for Use in Design. The formulas which follow are based upon assumptions, some of which are not entirely borne out by experimental data. The Committee of the Am. Soc. C. E. recommends that in the interests of simplicity and uniformity they be used until more rational methods appear to replace them.

Notation. 1. RECTANGULAR BEAMS. f_s = tensile unit stress in steel; f_c = compressive unit stress in concrete; E_s = modulus of elasticity of steel; E_c = modulus of elasticity of concrete; $n = E_s/E_c$; M = moment of resistance, or bending moment in general; A = steel area; b = breadth of beam; d = depth of beam to center of steel; k = ratio of depth of neutral axis to effective depth d; z = depth of resultant compression below top; j = ratio of lever arm of resisting couple to depth d; $jd = d - z$ = arm of resisting couple; p = steel ratio, not percentage.

2. T-BEAMS. b = width of flange; b' = width of stem; t = thickness of flange.

3. BEAMS REINFORCED FOR COMPRESSION. A' = area of compressive steel; p' = steel ratio for compressive steel; f_s' = compressive unit stress in steel; C = total compressive stress in concrete; C' = total compressive stress in steel; d' = depth to center of compressive steel; z = depth to resultant of C and C'.

4. SHEAR AND BOND. V = total shear; v = shearing unit stress; u = bond stress per unit area of bar; o = circumference or perimeter of bar; Σo = sum of the perimeters of all bars.

5. COLUMNS. A = total net area; A_s = area of longitudinal steel; A_c = area of concrete; P = total safe load.

Formulas. 1. RECTANGULAR BEAMS.

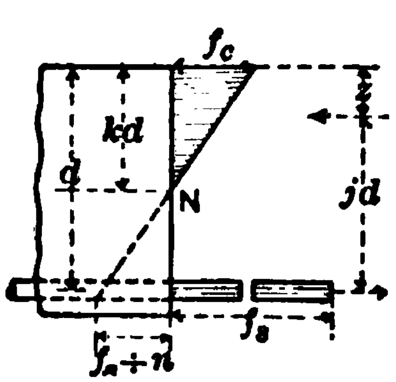


Fig. 46

Position of neutral axis,

$$k = \sqrt{2pn + (pn)^2} - pn \quad (1)$$

Arm of resisting couple,

$$j = 1 - \tfrac{1}{3}k \quad (2)$$

Note: For f_s = 15 000 to 16 000, and f_c = 600 to 650, k may be taken at $\tfrac{3}{8}$.

Fiber stresses,

$$f_s = \frac{M}{Ajd} = \frac{M}{pjbd^2} \quad (3)$$

$$f_c = \frac{2M}{jkbd^2} = \frac{2pf_s}{k} \quad (4)$$

Steel ratio, for balanced reinforcement,

$$p = \tfrac{1}{2}\,\frac{1}{\dfrac{f_s}{f_c}\left(\dfrac{f_s}{nf_c} + 1\right)} \quad (5)$$

2. T-BEAMS.

Case 1. When the neutral axis lies in the flange use formulas for rectangular beams.

Case 2. When the neutral axis lies in the stem. The following formulas neglect the compression in the stem:

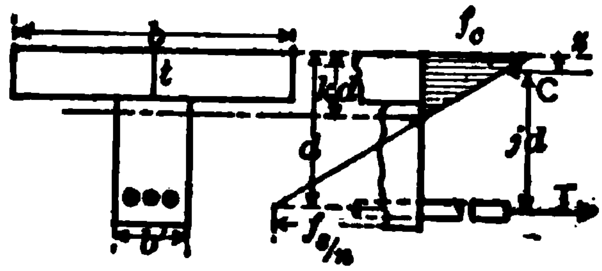


Fig. 47

Position of neutral axis,

$$kd = \frac{2\,ndA + bt^2}{2\,nA + 2\,bt} \quad \ldots \ldots \quad (6)$$

Position of resultant compression,

$$z = \frac{3\,kd - 2t}{2\,kd - t}\,\frac{t}{3} \quad \ldots \ldots \quad (7)$$

Arm of resisting couple,

$$jd = d - z \quad \ldots \ldots \quad (8)$$

Fiber stresses,

$$f_s = \frac{M}{Ajd} \quad \ldots \ldots \quad (9)$$

$$f_c = \frac{Mkd}{bt\,(kd - \tfrac{1}{2}t)\,jd} = \frac{f_s}{n}\,\frac{k}{1-k} \quad \ldots \ldots \quad (10)$$

Note: For approximate results, the formulas for rectangular beams may be used.

The following formulas take into account the compression in the stem; they are recommended where the flange is small compared with the stem:

Position of neutral axis,

$$kd = \sqrt{\frac{2\,ndA + (b - b')\,t^2}{b'} + \left(\frac{nA + (b - b')\,t}{b'}\right)^2} - \frac{nA + (b - b')\,t}{b'} \quad . \quad (11)$$

Position of resultant compression,

$$z = \frac{(kdt^2 - \tfrac{2}{3}t^3)\;b + [(kd - t)^2\,\{t + \tfrac{1}{3}(kd - t)\}]\,b'}{t\,(2\,kd - t)\,b + (kd - t)^2\,b'} \quad \ldots \quad (12)$$

Arm of resisting couple,

$$jd = d - z \quad \ldots \ldots \quad (13)$$

Fiber stresses,

$$f_s = \frac{M}{Ajd} \quad \ldots \ldots \quad (14)$$

$$f_c = \frac{2\,Mkd}{[(2\,kd - t)\,bt + (kd - t)^2\,b']\,jd} \quad \ldots \ldots \quad (15)$$

3. BEAMS REINFORCED FOR COMPRESSION.

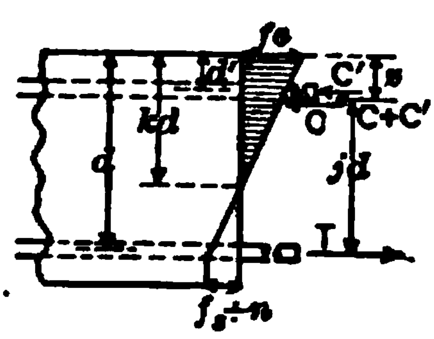


Fig. 48

Position of neutral axis,

$$k = \sqrt{2\,n\left(p + p'\,\frac{d'}{d}\right) + n^2\,(p + p')^2} - n\,(p + p') \quad . \quad (16)$$

Position of resultant compression,

$$z = \frac{\tfrac{1}{3}\,k^3 d + 2\,p'\,nd'\left(k - \frac{d'}{d}\right)}{k^2 + 2\,p'\,n\left(k - \frac{d'}{d}\right)} \quad \ldots \quad (17)$$

Arm of resisting couple,

$$jd = d - z \quad \ldots \ldots \quad (18)$$

Fiber stresses,

$$f_c = \frac{6\,M}{bd^2\left[3\,k - k^2 + \frac{6\,pn}{k}\left(k - \frac{d'}{d}\right)\left(1 - \frac{d'}{d}\right)\right]} \quad \ldots \ldots \quad (19)$$

$$f_s = \frac{M}{pjbd^2} = nf_c\,\frac{1-k}{k} \quad \ldots \quad (20) \qquad f'_s = nf_c\left[\frac{k - \frac{d'}{d}}{k}\right] \quad \ldots \quad (21)$$

4. SHEAR, BOND, AND WEB REINFORCEMENT. In the following formulas, Σo refers only to the bars constituting the tension reinforcement at the section in question, and jd is the lever arm of the resisting couple at the section.

For rectangular beams,

$$v = \frac{V}{bjd} \quad \ldots \ldots \ldots \quad (22) \qquad u = \frac{V}{jd\Sigma o} \quad \ldots \ldots \ldots \quad (23)$$

Note: For approximate results, j may be taken at $\frac{7}{8}$.

The stresses in web reinforcement may be estimated by the following formulæ:

Vertical web reinforcement, $$P = \frac{Vs}{jd} \quad \ldots \ldots \quad (24)$$

Web reinforcement inclined at 45°, not bent-up bars, $P = 0.7 \frac{Vs}{jd}$ . . . . . . (25)

in which P = stress in single reinforcing member, V = amount of total shear as carried by the reinforcement, and s = horizontal spacing of the reinforcing members.

The same formulæ apply to beams reinforced for compression as regards shear and bond stress for tensile steel.

For T-beams,

$$v = \frac{V}{b'jd} \quad \ldots \ldots \ldots \quad (26) \qquad u = \frac{V}{jd\Sigma o} \quad \ldots \ldots \ldots \quad (27)$$

Note: For approximate results, j may be taken at $\frac{7}{8}$.

5. Columns.

Total safe load, $$P = f_c\,(A_c + nA_s) = f_c\,A\,[1 + (n-1)\,p] \quad \ldots \ldots \quad (28)$$

Unit stresses,

$$f_c = \frac{P}{A\,[1 + (n-1)\,p]} \quad \ldots \quad (29) \qquad f_s = n\,f_c \quad \ldots \ldots \quad (30)$$

15. Iron and Steel

Definitions. Cast iron, wrought iron, and steel are called the ferrous metals, and are commonly known under the name of iron and steel. The iron ore mined in the United States is chiefly hematite, Fe_2O_3, the most noteworthy deposits being in the region of Lake Superior. The ore is taken to blast furnaces, where it is smelted and cast into a form known as pig iron. This in turn is carried thru different processes of refinement and converted into the ferrous metals. The following descriptions of cast iron, steel and wrought iron are given by Stoughton (53).

"Cast Iron is impure and weak, and must be brought to its desired size and form by melting and casting in a mold. A typical example would contain about 94% iron, 4% carbon, and 2% of other ingredients or impurities. Gray cast iron is weak and brittle. Pig iron is a raw form of cast iron. Malleable cast iron is a semi-purified form and when first made is cast in the condition of cast iron, and is made malleable by subsequent treatment without fusion. After cooling, the castings are cleaned and packed in some pulverized material, as iron ore, lime, or sand, and placed in an annealing furnace and heated to a temperature of about 705° C (1300° F) at which temperature they are kept for many hours after which they are allowed to cool slowly. The material is then greatly increased in strength and ductility. Only comparatively thin castings can be thus treated.

"Steel is purer than cast iron, much stronger, and may be produced in the desired size and form either by melting and casting in a mold or by forging at a red heat. It usually contains about 98% or more of iron, and, in different samples, from 1.5% down to almost no carbon, together with small amounts of other ingredients or impurities.

"Wrought Iron is almost the same as the very low carbon steels, except, that it is never produced by melting and casting in a mold, but is always forged to the desired size and form. It usually contains less than 0.12% of carbon. Its chief distinction from the low carbon steels is that it is made by a process which finishes it in a pasty, instead of a liquid form and leaves about 1 or 2% of slag mechanically disseminated thru it. The method is known as the puddling process in which pig iron is melted on the hearth of a reverberatory furnace until it assumes a pasty stage, in which slag is prominent. Balls of the material are squeezed and rolled into bars which are placed together, reheated and rolled into a smaller size known as the merchant bar."

The Purification of Pig Iron, in order to obtain structural steel, is accomplished by one of two methods: (1) BESSEMER, (2) OPEN HEARTH. In the Bessemer process, generally about 10 tons of pig iron are melted and put in a converter. Air is then forced thru the liquid mass, which produces an oxidation of the carbon and other elements contained in the iron. After about 10 min, the operation is stopped and the molten iron is recarburized by adding carbon and other elements. The iron is poured into ingots which are then ready for the mill. In the open hearth process, the pig iron, together with steel scrap, is placed upon a long shallow hearth, over which an intense flame is burning. The capacity of the furnace is from three to seven times that of the Bessemer converter and the time required for purification is from 6 to 10 hr. The molten material is then recarburized and cast into ingots. This method has become the most common one in use for structural steel.

Crucible or Cast Steel is made from wrought iron, by placing small pieces of the iron, together with the required amount of carbon and other elements, in small covered crucibles and melting, and pouring into small ingots. This grade of steel is used for tools, springs, etc, and is of high quality.

Alloy Steels are steels to which a controlling amount of some alloying element in addition to carbon is added, and this term is used to distinguish them from the so-called carbon steels, which are more common. As a general rule, the alloying element is added at the time of recarburizing. NICKEL STEELS are the most important of this class and are used in structural work where a greater elastic limit is desired, as well as a tougher material. Other alloy steels less used are VANADIUM, CHROMIUM, SILICON and MANGANESE STEELS.

Corrosion of Iron and Steel. The ferrous metals must be protected in some way against corrosion. Ferric hydroxide is formed wherever the metal is exposed to the action of water and air, which shows itself as a brown powder, commonly called rust. The most common method of protection is to form a coating over the exposed surface by painting or galvanizing. Paint is most used for material in such structures as bridges. It is usually stated that cast iron corrodes less rapidly than wrought iron and steel, and wrought iron less rapidly than steel. Some authorities question this statement. It should be noted, that when iron is cast in sand, a silicious coating, or skin, is formed on the casting which tends to protect it against rust. It is probable that the difference in speed of corrosion between wrought iron and steel is small. In bridges which have been allowed to remain unpainted for some time, a pitting effect is noticeable. This is probably due chiefly to blow holes. In repainting a bridge which has been neglected, it is important to remove all the scale and rust before applying the paint, as such places will usually continue to corrode under the paint, or else will tend to form loose spots from which the scale and paint will fall away, exposing the metal to the elements. See Sect. 27 and (53).

Annealing is the name given to the process of very slow cooling of metal which gives a steel relatively soft, but reduces its ultimate strength and elastic limit. If the steel is cooled by being thrown on sand, it will be medium soft. If artificial means are taken to cool the specimen, such as plunging into oil, water or mercury, it becomes hard, and relatively brittle. The usual purpose in annealing rolled steel shapes is to remove existing coarseness of grain. The following recommended practice for annealing is taken from the specifications of the Am. Soc. Test. Mat. (63 d).

"**Annealing Temperature.** In general, the higher the carbon content, the lower should be the annealing temperature. The following ranges of temperature should be used for the several ranges of carbon content indicated. They refer to the usual moderate manganese content. For steels with a manganese content greater than 0.75% slightly lower temperatures suffice.

Range of Carbon Content	Range of Annealing Temperature
Less than 0.12%	875° to 925° C (1607° to 1697° F)
0.12 to 0.29%	840° to 870° C (1544° to 1598° F)
0.30 to 0.49%	815° to 840° C (1499° to 1544° F)
0.50 to 1.00%	790° to 815° C (1454° to 1499° F)

"**Cooling.** After the object has been held at the annealing temperature long enough to make its temperature nearly uniform thruout, and to complete the refining of the grain, it should be cooled in a way suited to its carbon content and to giving it the specific properties needed. The general principles are: (1) the higher the carbon the slower should be the cooling; and (2) the slower the cooling the softer and more ductile the metal will be, and the lower will be its tensile strength, elastic limit, and yield point. The greatest softness and ductility are obtained at a certain sacrifice of strength and elasticity, and the greatest strength and elasticity at a certain sacrifice of softness and ductility. For most purposes neither of these extremes is desired, and it is not only sufficient as regards quality but economical to remove the object from the furnace as soon as it has been thoroly annealed, and to allow it to cool in air, always completely protected not only from rain and snow but from sharp drafts of air. Objects containing more than 0.5% of carbon should cool more slowly till the color dies out, say at 500° C (932° F), as for instance by leaving them in the furnace. They may then be removed and cooled in air. Further, thin objects containing between 0.25 and 0.50% of carbon should be treated like those of 0.5% of carbon unless they can be so massed together that their collective bulk will retard their cooling, so that they will collectively cool even in air with moderate slowness, like single large objects.

"To Give the Greatest Softness and Ductility of which the metal is capable, even at a certain sacrifice of strength and elastic limit, for instance for ease of machining or to resist a small number of severe distortions, the metal should be cooled slowly, either within the furnace, or in the case of large objects, under a cover of lime, clay, or other slow conductor of heat. The slower the cooling and the lower the temperature to which slow cooling is carried, the softer and weaker will the steel be. But for most cases for which even unusual softness and ductility are required, it suffices to remove the object from the furnace when it has become dead black, and to cool it thenceforth in air.

"To Give Great Tensile Strength and High Elastic Limit even at a certain sacrifice of ductility, the cooling should be more rapid, the rapidity to be governed by the thickness and carbon content of the object. Thin objects and those with high carbon content cannot stand so rapid a cooling as thick and low carbon ones, lest their ductility be too far sacrificed. For instance, thick objects with less than 0.5% of carbon may be cooled completely in air, of course protected from rain or snow. Objects with 0.5% of carbon or more, and thin objects with from 0.3 to 0.5% of carbon may be cooled in air if their cooling is somewhat retarded, as for instance by massing them together, as happens in the case of rails."

Am. Soc. Test. Mat. Specifications Covering Iron and Steel. For specifications for STRUCTURAL STEEL FOR BRIDGES, NICKEL STEEL, REFINED WROUGHT IRON BARS, GRAY IRON CASTINGS, MALLEABLE CASTINGS, WROUGHT IRON PLATES, FOUNDRY PIG IRON, CAST IRON PIPE, AND WIRE, see (63).

16. Timber

Definitions. The following standard names for structural timber are recommended by the Am. Soc. Test. Mat. (63p).

SOUTHERN YELLOW PINE. Under this heading two classes of timber are used: (1) Long-leaf pine, (2) short-leaf pine. It is understood that these two terms are descriptive of quality, rather than of botanical species. Thus, short-leaf pine would cover such species as are known as North

Carolina pine, loblolly pine, and short-leaf pine. Long-leaf pine is descriptive of quality, and if Cuban, short-leaf, or loblolly pine is grown under such conditions that it produces a large percentage of hard summer wood, so as to be equivalent to the wood produced by the true long-leaf, it would be covered by the term long-leaf pine.

Douglas Fir. The term Douglas fir is to cover the timber known likewise as yellow fir, red fir, Western fir, Washington fir, Oregon or Puget Sound fir or pine, Northwest and West coast fir.

Norway Pine, to cover what is known also as Red Pine.

Hemlock, to cover Southern or Eastern hemlock; that is, hemlock from all States east of and including Minn.

Western Hemlock, to cover hemlock from the Pacific coast.

Spruce, to cover Eastern spruce; that is, the spruce timber coming from points east of Minn.

Western Spruce, to cover the spruce timber from the Pacific coast.

White Pine, to cover the timber which has hitherto been known as white pine, from Me., Mich., Wis. and Minn.

Idaho White Pine, the variety of white pine from western Mont., northern Idaho, and eastern Wash.

Western Pine, to cover the timber sold as white pine coming from Ariz., Cal., N. Mex., Col., Ore. and Wash. This is the timber sometimes known as Western Yellow Pine, or Ponderosa Pine, or California White Pine, or Western White Pine.

Western Larch, to cover the species of larch or tamarack from the Rocky Mountain and Pacific coast regions.

Tamarack, to cover the timber known as Tamarack, or Eastern Tamarack, from States east of and including Minn.

Redwood, to include the California wood usually known by that name.

Life of Timber. Such trees as birch, beech and maple should never be used for the manufacture of structural timbers, except as a temporary makeshift, or where an excessive wear requires the replacing of the timber at short intervals. Such woods are of only 3 or 4 years' duration under good conditions. Table VI gives the approximate life of timber. The last column shows the life of timber after some good preservative treatment. The data is based upon conditions which would exist for railroad cross-ties.

Table VI.—Approximate Life of Timbers

Kind	Without Treatment Years	With Treatment Years
Redwood	12	..
Cypress	10	..
White oak	8	..
Long-leaf pine	7	20
Douglas fir	6	15
Spruce	6	14
White pine	5	14
Hemlock	5	15
Red oak	4	20
Beech	4	20
Maple	4	18
Loblolly pine	3	15

Preservative Treatments. Timbers of the more durable species when placed upon concrete or stone piers, out of contact with the ground, in

many cases will outlive their mechanical life without treatment with a wood preservative. When the timber comes in contact with the ground, it is often economical to use some one of the methods for prolonging its life. The method of treatment depends upon the species, and upon conditions. In the case of sapwood being present, preservation is necessary and by proper treatment inferior species and sticks showing sap can be economically used that would otherwise be unfit. It should be noted that sapwood does not weaken the carrying power of the piece. Timber to be subjected to ground contact should be treated by the full cell creosote process with an injection of 10 to 12 lb per cu ft. In this process, the timber is thoroly seasoned in air and then placed in a treating cylinder, a vacuum drawn, and the creosote introduced under a pressure of 125 to 150 lb per sq in. When the required penetration has been obtained, the excess oil is drained off and a vacuum drawn for the purpose of drying. Variations of the method are to omit the first vacuum; to steam the timber for further seasoning before introducing the creosote; and to steam after impregnation. Cost of treating varies with the oil specifications and the amount of oil to be injected. Probably on a thousand board feet basis, treatment with 14 lb of creosote per cu ft would cost in the vicinity of $25 per thousand. Where ground conditions are not severe, the empty cell process may be sufficient. This method simply saturates the cell walls and no free preservative is left in the cell. Five to 6 lb of creosote per cu ft should be sufficient. Processes for the empty cell treatment vary, immersion in a tank of the oil being common. Where impregnation treatments can not be applied, brush application of hot coal-tar creosote is next in efficiency. The timber should be thoroly air seasoned and dry before applying the creosote and season cracks should be filled. The temperature of the creosote should be at about 66° C (150° F). Paint does not adhere well to creosoted timber.

Planking. The requisites of good planking are strength, resistance to mechanical wear, durability and ability to hold spikes well. Southern yellow pine makes the best planking and should be used in preference to other species when it can be economically obtained. White pine, cypress, oak and redwood are generally too valuable for other purposes to be used for planking. Spruce is to be recommended, and hemlock is satisfactory, where splintering will not be objectionable and where the structure is not subjected to heavy shocks. Hemlock is particularly good in nail holding qualities. Douglas fir is also an excellent planking.

Specifications and Grading. For bridge timbers and planking the material should be free of loose knots, or knots of large size. A small sound knot does not weaken the piece to any extent, but such knots should not be present in large numbers. Rot should not be present at all. Sap stain, called blue sap rot, is not objectionable unless the discoloration is undesirable, as this rot does not impair the strength or durability of the wood. Season checks or cracks, if long and deep, should not be permitted. Small season checks will be found in the ends of nearly all large timbers. Timbers and planks should be well seasoned and shrunk to their permanent size before creosoting or laying. Seasoning reduces the moisture content of the wood and increases the strength of the piece. Timbers are usually sawn from the heart of the log so that inclusion of sap is avoided. Heartwood timbers are preferred because of the greater liability of the sapwood to decay. Where the timber is to be impregnated with creosote, the sapwood need not be excluded, but its use is not advisable when no treatment or a very

superficial, light brush, one is employed. Standard specifications for yellow pine bridge and trestle timbers were adopted in 1910 by the Am. Soc. Test. Mat. (63 n).

Strength of Timber. Table VII (8) shows the working unit stresses for structural timber as given by the Am. Ry. Eng. Assn. The working unit stresses are intended for railroad bridges. For highway bridges and trestles, they may be increased 25%.

Table VII.—Unit Stresses of Timber in Pounds per Square Inch

Kind of Timber	Bending			Shearing			
	Extreme Fiber Stress		Modulus of Elasticity	Parallel to the Grain		Longitudinal Shear in Beams	
	Average Ultimate	Working Stress	Average	Average Ultimate	Working Stress	Average Ultimate	Working Stress
Douglas fir	6100	1200	1 510 000	690	170	270	110
Long-leaf pine	6500	1300	1 610 000	720	180	300	120
Short-leaf pine	5600	1100	1 480 000	710	170	330	130
White pine	4400	900	1 130 000	400	100	180	70
Spruce	4800	1000	1 310 000	600	150	170	70
Norway pine	4200	800	1 190 000	590*	130	250	100
Tamarack	4600	900	1 220 000	670	170	260	100
Western hemlock	5800	1100	1 480 000	630	160	270*	100
Redwood	5000	900	800 000	300	80	....	....
Bald cypress	4800	900	1 150 000	500	120	....	....
Red cedar	4200	800	800 000	....	..	....	....
White oak	5700	1100	1 150 000	840	210	270	110

Kind of Timber	Compression					
	Perpendicular to the Grain		Parallel to the Grain		Working Stresses for Columns	
	Elastic Limit	Working Stress	Average Ultimate	Working Stress	Length Under $15 \times d$	Length Over $15 \times d$
Douglas fir	630	310	3600	1200	900	$1200\ (1 - L/60d)$
Long-leaf pine	520	260	3800	1300	975	$1300\ (1 - L/60d)$
Short-leaf pine	340	170	3400	1100	825	$1100\ (1 - L/60d)$
White pine	290	150	3000	1000	750	$1000\ (1 - L/60d)$
Spruce	370	180	3200	1100	825	$1100\ (1 - L/60d)$
Norway pine	....	150	2600*	800	600	$800\ (1 - L/60d)$
Tamarack	....	220	3200*	1000	750	$1000\ (1 - L/60d)$
Western hemlock	440	220	3500	1200	900	$1200\ (1 - L/60d)$
Redwood	400	150	3300	900	675	$900\ (1 - L/60d)$
Bald cypress	340	170	3900	1100	825	$1100\ (1 - L/60d)$
Red cedar	470	230	2800	900	675	$900\ (1 - L/60d)$
White oak	920	450	3500	1300	975	$1300\ (1 - L/60d)$

Unit stresses are for green timber and are to be used without increasing the live load stresses for impact.

* Values noted are for partially air dry timbers. L is length of column in inches, d is least side or diameter in inches.

Weight of Timber. Table VIII (8) gives the weight of seasoned timber in pounds per cubic feet where the moisture content is from 15 to 20%. Green timber has a moisture content of up to 50%.

Table VIII

	Pounds per Cubic Foot
Ash, white-red	40
Cedar, white-red	22
Chestnut	41
Cypress	30
Fir, Douglas spruce	32
Fir, eastern	25
Elm, white	45
Hemlock	29
Hickory	49
Locust	46
Maple, hard	43
Maple, white	33
Oak, chestnut	54
Oak, live	59
Oak, red, black	41
Oak, white	46
Pine, Oregon	32
Pine, red	30
Pine, white	26
Pine, yellow, long-leaf	44
Pine, yellow, short-leaf	38
Poplar	30
Redwood, California	26
Spruce, white, black	27
Walnut, black	38
Walnut, white	26

17. Structural Stone

Kinds. The most important stones from the viewpoint of the engineer may be divided into granite, limestone, sandstone and trap. Marble should also be included, altho it really comes under limestone.

Classification. Stone may be classified according to geological position, chemical composition, and physical structure. See Sect. 3.

Compressive Strength and Weight. These values vary widely for the same material, depending upon methods of testing, and quality of the stone. Table IX (36) gives average values. For further data see (1), (16) and (27).

Table IX

Kind	Pounds per Cubic Foot	Specific Gravity	Ultimate Compression Pounds per Square Inch
Granite	170	2.72	15 000
Limestone	170	2.72	6 000
Sandstone	150	2.40	8 000
Marble	170	2.72	10 000
Trap	185	2.96	20 000

GRANITE is the strongest and most durable of the building stones. It may be quarried with ease, although it is hard to work. It is used for foundations, buildings;

and also to some degree for decorative purposes. LIMESTONE is found in many colors and is used for decorative purposes as well as for nearly all purposes of construction. The stone may be soft when first quarried, but seasons on being exposed. Many of the limestones are easily worked and are of fair durability. SANDSTONE is composed chiefly of quartz cemented together. The harder varieties make good building stone. MARBLE is a limestone which is crystalline in structure and takes a good polish. There are many colors which make it an excellent stone for decorative purposes. TRAP is a tough rock found in certain localities, the best known being the New York Palisades. It is very hard to work, being used mostly for road construction.

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SECTION 3

ENGINEERING GEOLOGY

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ROCKS

1. Rock-Forming Minerals

Definitions. A mineral is an inorganic chemical compound, or rarely element, possessing characteristic physical properties, such as crystal form, cleavage and behavior with light, electricity and heat. A rock is any mineral or aggregate of minerals which forms an essential part of the earth. A rock must therefore appear in relatively large amounts. Each species of rock should be so established as to be fairly uniform in texture and mineral composition, but variability in both is always to be expected. Species of rock often shade insensibly into one another.

Rocks are Classified into three great groups: igneous, sedimentary and metamorphic. The IGNEOUS rocks have crystallized from a highly heated,

molten state, illustrated by the lava streams of volcanos. The SEDIMENTARY rocks embrace: (1) rocks formed of fragments of older rocks; (2) remains of living organisms, and (3) precipitates from solution in the few cases where they are abundant enough to be an essential part of the earth. The METAMORPHIC rocks are those igneous and sedimentary originals which have undergone such serious changes from geological processes as to have their original characters disguised. Doubt may arise as to what they once were, so that they are advantageously grouped by themselves.

The Minerals of the Igneous Rocks. The chemical compounds which most frequently appear in the minerals of the igneous rocks are, in order, silicates, oxides, sulphides and one phosphate. The silicates are practically all salts of the following three silicic acids: H_4SiO_4, $H_4Si_2O_6$, and $H_4Si_3O_8$. Since silica, SiO_2, is the acid radical of each, those igneous rocks which have a high percentage of silica, 65 to 80, are called acidic; while those which are low, 30 to 50, are called basic, because the bases are relatively abundant; intermediate percentages, 50 to 65, embrace the medium rocks. The gross composition of the outer rocky crust of the earth, as estimated by F. W. Clarke, Chief Chemist, U. S. Geol. Survey, and as given under A, Table I, is that of a medium igneous rock. The average composition calculated from many thousands of analyses of igneous rocks by H. S. Washington, of the U. S. Geol. Survey, and as given under B, in Table I, is practically the same:

Table I.—Average Chemical Composition of Rocks

	A	B		A	B		A	B
SiO_2....	59.85	58.24	FeO...	3.35	3.87	Na_2O..	3.29	3.91
Al_2O_3...	14.87	15.80	MgO..	3.77	3.84	K_2O...	3.02	3.16
Fe_2O_3...	2.63	3.33	CaO...	4.81	5.22	H_2O...	2.05	1.48

The rock-forming silicates which are highest in silica are orthoclase with 64.7%, and albite with 68.6%. No igneous rock could therefore exceed 68.6% silica without containing free silica. The acidic rocks, therefore, often contain free silica, crystallized as quartz.

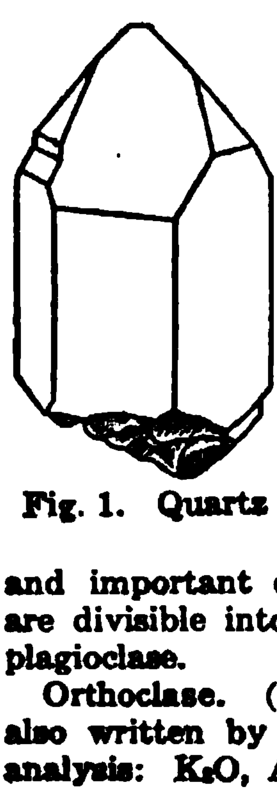


Fig. 1. Quartz

Quartz. (Sp. Gr. 2.65) Composition, SiO_2. When crystallized, quartz occurs in double six-sided pyramids, as in Fig. 1; or in corroded portions of the same; or in irregular individuals. Colorless, smoky, pale blue, or milky white. Glassy in appearance. No cleavage. Not scratched with a knife. In light colored rocks with abundant feldspar. Prismatic quartz does not appear in the igneous rocks; only in veins deposited from solution.

Feldspars are the most abundant and important components of igneous rocks. They are divisible into two great varieties, orthoclase and plagioclase.

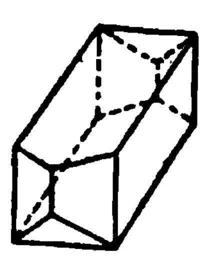


Fig. 2. Orthoclase

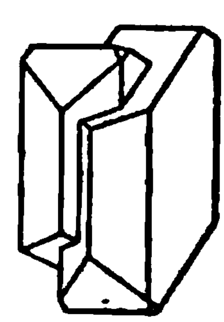


Fig. 3. Orthoclase Carlsbad Twin

Orthoclase. (Sp. Gr. 2.57) Composition, $KAlSi_3O_8$, also written by doubling, so as to represent the components as determined by analysis: K_2O, Al_2O_3, $6SiO_2$; SiO_2, 64.7%; Al_2O_3, 18.4%; K_2O, 16.9%. To some extent Na_2O replaces the K_2O. Crystal forms, as in Figs. 2 and 3; also in corroded

portions of the same; and in irregular individuals. Reddish, white, greenish. Two good cleavages meeting at a right angle, one pearly. Other features irregular. Only scratched with very hard steel. Chiefly in light colored rocks, of which it may be the chief component. Alters with loss of K_2O and SiO_2 to kaolinite, $2H_2O$, Al_2O_3, $2SiO_2$. By its alteration to colloidal kaolinite, orthoclase contributes to the bond of macadam.

Plagioclase (Sp. Gr. 2.62 to 2.75) is the name of a group of feldspars embracing albite, $NaAlSi_3O_8$ or Na_2O, Al_2O_3, $6SiO_2$, anorthite, $CaAl_2Si_2O_8$ or CaO, Al_2O_3, $2SiO_2$, and all intermediate mixtures of the same, of which oligoclase with predominant albite, and labradorite with predominant anorthite are the most important.

Table II.—Composition of Plagioclase Feldspars

	SiO_2	Al_2O_3	CaO	Na_2O
Albite	68.6	19.5	....	11.8
Oligoclase	63.7	21.4	2.4	10.5
Labradorite	57.3	27.1	9.0	6.6
Anorthite	43.1	36.6	20.1	....

The analyses in Table II emphasize the presence of albite in the acidic rocks; of oligoclase in the acidic and medium; of labradorite in the medium or basic, and of anorthite in the basic. The plagioclases, when crystallized, have forms somewhat resembling Fig. 2; they are also corroded and irregular. Albite, as the name implies, is usually white; the others are white, gray, reddish, brown and green. Two good cleavages meeting at a visibly oblique angle; one cleavage face is usually marked with fine parallel striations (see Fig. 4) which may require a good lens for identification and which is the chief distinction from orthoclase. Other fractures irregular. Only scratched with very hard steel. In both light and dark colored rocks. Alters to kaolinite by loss of Na_2O; labradorite and anorthite yield calcite as well. All the plagioclases are valuable components of water-bound macadam; the acidic ones on weathering develop colloidal kaolinite for the bond; the basic ones yield in addition calcite, likewise good for the bond. The best rocks for macadam contain labradorite.

Fig. 4. Plagioclase

The Micas (Sp. Gr. 2.70 to 3.00) constitute a group of minerals all marked by a perfect cleavage along which they split into leaves of indefinite thinness. They are all salts of H_4SiO_4, and are varying mixtures of $KAlSiO_4$, $HAlSiO_4$, Mg_2Al_2, $3SiO_4$, Mg_2Fe_2 and $3SiO_4$. Sodium and calcium either fail or are very subordinate in the micas. The light colored micas, containing chiefly $KAlSiO_4$ and $HAlSiO_4$, are called MUSCOVITE, or sometimes potash mica. They are closely related to orthoclase in composition. The dark colored micas, rich in magnesium-bearing molecules are called BIOTITE, or sometimes magnesia mica. When well crystallized, both muscovite and biotite have the form of somewhat irregular hexagonal prisms. They far more frequently appear in irregular scales and shreds. Muscovite is colorless, gray or pale green; biotite is deep brown, green or black. Both are scratched by the thumb-nail or with a copper coin. Muscovite as an original mineral is limited to the granites among the igneous rocks. Biotite may appear in igneous rocks of all compositions. The alteration of orthoclase under thermal waters often produces fine, scaly secondary muscovite, called sericite. The micas are not good components of rocks used in macadam, because of the slippery nature of their cleavage flakes. They prevent effective bond. In relatively small amount, their influence is slight.

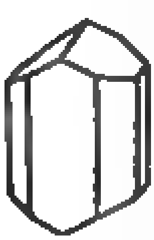


Fig. 5. Pyroxene. Crystal Form

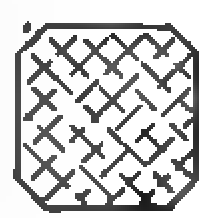


Fig. 6

The Pyroxenes (Sp. Gr. 3.10 to 3.60) are all salts of H_2SiO_3, and range from simple silicates of magnesia and lime to very complicated ones containing alumina, ferrous and ferric iron, manganese and soda; potash is lacking in pyroxenes. The pyroxenes

in the rocks used for macadam are chiefly the complex silicates known as augite. The pyroxenes crystallize in forms like Figs. 5 and 6 and develop eight-sided prisms, but are also in irregular individuals. They all have a prismatic cleavage with planes meeting nearly at a right angle, 87° to 93°. Colors: green, brown, or black. Scratched with a knife. While the pyroxenes do not entirely fail in the acidic rocks, they are much more prominent in the medium rocks, and reach a predominant point in the basic. They are valuable components of macadam, because they withstand wear fairly well, and afford, on weathering, calcite, hydrates of iron, and a hydrated silicate of magnesium and iron, called chlorite, which presumably has colloidal properties.

The Amphiboles (Sp. Gr. 2.90 to 3.50) are all salts of H_2SiO_3, and are closely parallel with the pyroxenes in composition. They differ from them in crystal form, as shown by Fig. 7, being usually six-sided prisms. They also appear in irregular individuals. They all have prismatic cleavage, with planes meeting at nearly 120° (124°–56°). See Fig. 8. This contrast in the angle of cleavages with the nearly 90° of the pyroxenes is the only way of distinguishing the minerals in the hand specimen. Colors: green, brown and black; most often black. Scratched by a knife. The dark amphibole of complex composition, corresponding to augite among the pyroxenes, is called hornblende. The amphiboles, chiefly the variety hornblende, appear in igneous rocks of all compositions, but they are least frequent in the basalts. Amphiboles are valuable components of macadam, and are extremely tough. They weather as do the pyroxenes.

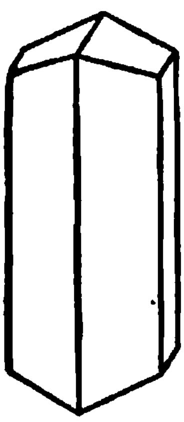


Fig. 7. Amphibole, Hornblende

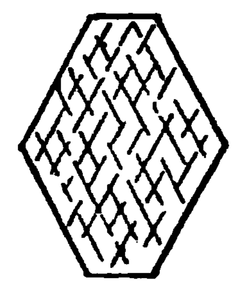


Fig. 8

Olivine (Sp. Gr. 3.30 to 3.60), the only remaining mineral of the first order of importance in the igneous rocks, is a salt of H_4SiO_4, the bases being magnesia and ferrous iron, in varying proportions. Irregular individuals are more common than shaped crystals. Color, olive green. No good cleavage. Only scratched with a file. Olivine appears in the basic rocks, and in them is a characteristic and widespread component.

Many Minor Silicates are found in the igneous rocks, of which only a few names will be given. The group of the feldspathoids, embracing minerals related to the feldspars, embraces nephelite leucite and melilite. Their rocks are too rare to be described in a work for engineers. There are some silicates which are microscopic and widely distributed, such as zircon, titanite and garnet.

Magnetite, FeO,Fe_2O_3, is a black, opaque, heavy mineral, which in small irregular individuals seldom fails in any igneous rock, but is rarely in quantity deserving serious attention. It may be intercrystallized with, or associated with, ilmenite, FeO,TiO_2, and is then described as titaniferous magnetite. The sulphides, pyrite, FeS_2, and pyrrhotite, Fe_7S_8, are also widespread in small particles. By oxidizing they develop ferric hydrate and may help the bond.

Apatite, the phosphate and chloride of lime, is a minute component of every kind of igneous rock, but in such small quantities as to be negligible.

No other minerals, original in the igneous rocks, merit serious attention from highway engineers, altho there are of course a large number of rare components.

The Minerals of the Sedimentary Rocks. When the igneous rocks disintegrate, they contribute their undecomposed minerals and their alteration products to the sedimentary. Quartz, which is very resistant to change, is, therefore found as the commonest mineral in the fragmental sediments. With it are associated feldspars, and to a far less degree the dark silicates. The feldspars undergo alteration by the loss of their alkalies or alkaline earth, so that kaolinite, $2H_2O$, Al_2O_3, $2SiO_2$, results, and at times, free silica. The darkest silicates change to chlorite, $2H_2O$, $2MgO$, (Al_2O_3, Fe_2O_3) SiO_2, a green scaly mineral. The basic feldspars and the calcareous pyroxenes and amphiboles yield calcite. No further descriptions need be given of quartz, the feldspars, and the other minerals which while still undecomposed enter the sediments. They appear in irregular grains, but are otherwise like the components of igneous rocks.

Kaolinite (Sp. Gr. 2.40 to 2.60). Composition, $2H_2O,Al_2O_3,2SiO_2$: SiO_2, 46.50%; Al_2O_3, 39.57%; H_2O, 13.93%. When pure, it is found in minute white scales; soft; unctuous; plastic. It is often mixed with comminuted quartz, forming kaolin. The mineral is seldom seen by itself, but enters into the muds and finer sediments which settle in still water. See Art. 8.

Flint and Chert are forms of silica, SiO_2, precipitated from solution. They are dense, almost glassy in appearance, harder than steel, and break with a curving fracture. They occur either as rounded nodules, flint, or as very irregular streaks and masses, chert, usually in limestone or chalk. They differ from quartz in not being definitely crystalline, never showing any crystal form. Color: black, reddish, or shades of gray. Flint and chert occur in enormous amount in many limestone formations, usually rendering the rock useless for building or cement-making purposes. When the soluble limestone weathers out, the flint remains, forming beds. Flint is sometimes used as road metal, but its very low cementing value and habit of breaking with hard sharp edges are against its use.

Calcite (Sp. Gr. 2.70). Composition, $CaCO_3$; CaO, 56%; CO_2, 44%. It is often intimately mingled with $MgCO_3$; easily scratched; cleaves in rhombohedrons; white, bluish, brownish; effervesces with nearly all acids, especially when powdered. Calcite is the basis of limestones and is a widespread and important mineral. Because of its easy solubility and redeposition, calcite supplies a valuable bond in macadam.

Dolomite (Sp. Gr. 2.80 to 2.90). Composition, $CaCO_3,MgCO_3$: CaO, 30.43%; MgO, 21.72%; CO_2, 47.85%: $CaCO_3$, 54.35%; $MgCO_3$, 45.65%. It is a little harder than calcite, which it otherwise closely resembles. Cleaves in rhombohedrons. Color: white, pink, pearly. Effervesces with hot acid. Powder is more easily affected than solid pieces. Dolomite often constitutes entire strata, but all transitions from pure calcite to pure dolomite are found. The feeble or hot effervescence is the best distinction. In macadam it supplies a bond, much as does calcite.

In the sedimentary rocks, we also find gypsum, anhydrite, rock-salt, coal, and several forms of silica or hydrated silica other than quartz, etc, but none of these minerals are important in highway work.

Minerals of the Metamorphic Rocks. With the possible exception of olivine, all the minerals of the igneous rocks and also the kaolinite, calcite and dolomite of the sedimentaries appear in the metamorphic rocks. There are also some additional silicates as follows:

Garnet (Sp. Gr. 3.00 to 4.00) is really a group of minerals of which almandite, $3FeO,Al_2O_3,3SiO_2$, is characteristic of the gneisses and schists; and grossularite, $3CaO,Al_2O_3,3SiO_2$, of the crystalline limestones. Very hard, not scratched with steel. Color, red and brown. Often well crystallized. Of small importance in macadam because of its rarity.

Chlorite (Sp. Gr. 2.60 to 2.80) is really the name of a group of hydrated silicates of magnesium, aluminum and ferric iron. Two common molecules are $2H_2O,2MgO,Al_2O_3,SiO_2$, and $2H_2O,2MgO,Fe_2O_3,SiO_2$. Chlorite is green, often scaly, soft, and is the ordinary alteration product of pyroxenes, amphiboles and biotite.

Serpentine, $2H_2O,3MgO,2SiO_2$, sometimes with FeO replacing part of the MgO. Green, red or brown; massive to fibrous; soapy to the feel. Its hardness varies from very soft to a grade scratched with difficulty with a knife. Derived from olivine and the ferro-magnesian pyroxenes and amphiboles by alteration which is believed to take place quite far below the earth's surface. Both chlorite and serpentine are soft minerals under wear, and powder to a slippery mass, as do all richly magnesian minerals.

Besides the minerals mentioned there are a large series of others such as epidote, staurolite, andalusite, sillimanite, cyanite and scapolite, which, while not infrequent in metamorphic rocks, are not sufficiently general to deserve mention.

2. Igneous Rocks

Texture of a rock means the relative sizes of the component grains or crystals. When the crystals are visible to the naked eye, and all of about equal size, the texture is called GRANITOID, because characteristically illustrated by common granite. A synonym is granular. The granitoid texture

varies from extremely coarse in the pegmatites, to fine grained varieties. The crystals are about the same size, about as long as broad, and usually shapeless and irregular. When granitoid texture becomes so fine that the unaided eye cannot detect the individual components, and can only recognize a fine grained mass, the texture is called FELSITIC. The microscope shows that felsitic rocks have the same minerals as the coarser igneous rocks, but they become extremely small. Felsitic texture results from a quick cooling of the molten magma, while the granitoid is the product of very slow cooling at great depth beneath the surface. Often after commencing to crystallize in depth and under heavy pressure, and producing a crop of large, well formed crystals of feldspars, quartz and dark silicates which swim in the still fluid mass, the magma is forced upward to or toward the surface and finally solidifies quickly under slight pressure. The older, larger crystals are thus caught in a felsitic mass. The texture is then called PORPHYRITIC. The large crystals are called PHENOCRYSTS, or visible crystals. The felsitic portion is called the ground-mass (see Fig. 9). Even in coarse granitoid rocks, feldspars may grow exceptionally large, and give a porphyritic aspect to the rock, which may then be called porphyritic granite, or granite porphyry. In the very quick chill of the eruptive rock, even volcanic GLASS may be formed, entirely analogous to blast furnace slag. The glass may contain phenocrysts washed up from depth, giving a porphyritic rock, with glassy ground-mass. Should the eruptive outbreak be explosive, both solid and molten rocks are blown to fragments, and distributed over wide areas, giving FRAGMENTAL igneous rocks. The following five textures are important: glassy, felsitic, porphyritic, granitoid, and fragmental.

Fig. 9. Rhyolite Porphyry

Igneous rocks depend for BOND upon the manner of interlocking of component crystals (see Fig. 10), a strength such as is derived in carpentry from dovetailing. Sedimentary rocks depend for bond upon the quality and arrangement of a cementing material distributed between and among the grains. No such material exists in igneous rocks. In Fig. 11, the grains are shaded, the cement is shown in black, and the voids or pores in white.

Fig. 10. Gray Granite, Maine

Igneous Rocks are Classified according to their composition and texture. Rocks having about the same chemical and mineralogical composition constitute a FAMILY. Within each family, the rocks are named according to their texture. Table III presents a condensed statement of the most important families of igneous rocks. The families are arranged from left to right in the order of acidity, and the average silica content of each is expressed in percentages at the bottom of each column. The textures are arranged from top to bottom, in order, from glassy to fragmental. No exact classification can be assigned to a glass, because by definition, no minerals have formed. It is enough to classify them as acid or basic glasses. The fragmental texture is likewise a special case, for the particles blown out are themselves of very variable texture, tho usually felsitic or glassy. The

Fig. 11. Sedimentary Rock

Table III.—Classification of Igneous Rocks

	Rhyolite Obsidian, Pumice, etc			Andesite Obsidian, etc			Basic Glasses, Scoria, etc	
	Orthoclase dominant ±Plagioclase, ±Biotite ±Hornblende		Plagioclase dominant ±Orthoclase ±Biotite ±Hornblende				No Feldspar, Pyroxene or Olivine dominant	
	+Quartz	−Quartz	+Quartz	−Quartz	Pyroxene −Olivine	Pyroxene +Olivine	−Olivine	+Olivine
					Basalt Group			
	Rhyolite Felsite	Trachyte Felsite	Dacite Felsite	Andesite Felsite	Augite Andesite	Basalt	Augitite	Limburgite
					Diabase Group			
	Rhyolite Porphyry	Trachyte Porphyry	Dacite Porphyry	Andesite Porphyry	Augite Andesite Porphyry Diabase	Basalt Porphyry Olivine Diabase	Augitite Porphyry	
					Gabbro Group			
	Granite Porphyry	Syenite Porphyry	Quartz Diorite Porphyry	Diorite Porphyry	Gabbro Porphyry Coarse Diabase	Olivine Gabbro Porphyry Coarse Olivine Diabase	Pyroxenite Porphyry	
	Granite	Syenite	Quartz Diorite	Diorite	Gabbro	Olivine Gabbro	Pyroxenite	
Fragmental	Rhyolite Tuffs and Breccias	Trachyte Tuffs and Breccias	Dacitic Tuffs and Breccias	Andesitic Tuffs and Breccias	Basaltic Tuffs and Breccias			
SiO_2	80 to 65%	65 to 55%	70 to 60%	65 to 50%	65 to 50%	55 to 45%	55 to 45%	

other textures from felsitic to granitoid compose an unbroken series, each type grading insensibly into the next succeeding type.

Identification of Igneous Rocks by Use of Table III: Examine the rock in the following steps: (1) Note its texture; glassy or crystalline; the presence or absence of ground-mass. (2) Determine its minerals; (a) the dominant feldspar, (b) presence or absence of quartz, (c) the chief dark mineral, biotite, hornblende, pyroxene or olivine. The texture places it in one of the horizontal columns, in Table III, and the mineral content determines the family, see vertical column, to which it belongs. (3) Name the rock, denoting both its texture and composition, as Rhyolite Porphyry, Gabbro, etc. For discussion of diabase, trap, see Art 2. (4) Now look for decay products, kaolin, chlorite, rust stains, etc, and for any structural weaknesses, cracks, poor interlocking, etc.

Mineral Associations that aid in determining igneous rocks:

1. Augite is very rare in granites and quartz diorites. A dark, rod-shaped silicate is probably hornblende.
2. Hornblende is far more common than aug'te in the light colored rocks generally.
3. Olivine never occurs in the same rock with quartz. A greenish mineral so present is probably epidote, an alteration product or metamorphic mineral.
4. Biotite may occur in any and all igneous rocks, its presence does not determine the rock. It is probably most richly abundant in the diorites.
5. If orthoclase in a rock is pink, all the orthoclase will commonly be pink. The white feldspar associated is probably plagioclase.
6. If orthoclase is white, all the orthoclase will be white, as well as the plagioclase. Great difficulty is encountered in distinguishing the feldspars, and naming the rock.

Occurrence of Igneous Rocks. All magma, or molten rock solution, must rise from unknown depths in the earth's interior, and must (1) either reach the surface, forming surface flows and ash beds, or (2) lodge somewhere in the earth's crust in some fissure or cavity. Rocks of type (1) are called EXTRUSIVE or VOLCANIC and those of type (2) are INTRUSIVE or PLUTONIC. The relations of the various types of intrusive and extrusive igneous bodies are shown diagrammatically in Fig. 12.

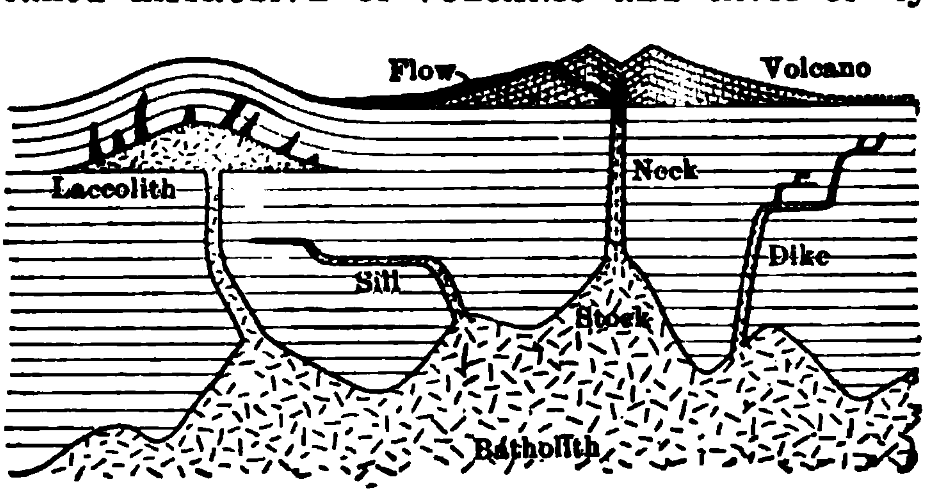


Fig. 12

The invading magma forms a great chamber for itself, possibly by breaking off and absorbing or melting the country rock thru which it rises, for the latter is almost never displaced or crumpled at the edges of the great igneous body. Such great igneous mass is called BATHOLITH. It may be hundreds of miles in extent, and no bottom is known for any batholith. From the top of the batholith, smaller subsidiary chambers arise, filled also with molten matter. These are called STOCKS or BOSSES, and, like the batholith, often fail to displace or crumple the rocks they penetrate. Nearly all quarried granite for structural material is taken out of stocks or batholiths. These great masses offer conditions of slow cooling and steady pressure under vast loads of overlying rocks, conducing toward uniformity and coarseness of grain in the resulting rock. From these larger masses, smaller bodies may penetrate the strata thru fissures, or along natural planes of weakness like bedding planes. If these sheet-like intrusives are parallel to the bedding, they are called SILLS. If they cut the bedding of the country rock, they are called DIKES. There is no essential difference between a dike and a sill, and, as the diagram shows, a dike may become a sill, or a sill a dike by changing its direction. If a large

molten mass rises to near the surface, it may push up the overlying strata in a dome-like uplift. The igneous mass would rudely resemble a plano-convex lens, lying on its flat face. It is called a LACCOLITH. The Henry Mountains, of Utah, and the Ortiz Mountains of New Mexico are examples of laccoliths, of which there are a number in the mountainous West. Thru a dike, or thru a circular vertical pipe-like opening in the rock, lava may reach the surface. That which wells out and runs on the surface is a LAVA-FLOW. Gases escaping violently from the magma, as pressure is released, may cast up vast amounts of fragmental rock, both of lava itself and of the country rock thru which it rises. These ejected fragments fall to earth, the heavier blocks near the vent, where they build a VOLCANIC CONE around the opening. The finer particles fall farther away, often very many miles distant; they often form beds of vast extent, and in places are used as road metal. They form cindery, dusty roads when dry, and muddy ones when wet.

The Glasses are seldom important to the highway engineer because of their limited occurrence. They often appear as layers of variable thickness, with clay or ash partings, where later eruptions have poured out upon older flows. They are much split and jointed vertically. Sometimes dense and glassy, called obsidian. Or the mass may have been blown full of small bubble-holes by expanding gases when the mass was liquid. These are called pumice when the bubbles are very small, forming a light rock-froth, and scoria when the vesicles are coarse and thick-walled. Pumice is more common in acid rocks, scoria in basic rocks. The rocks are unsatisfactory as road metal. Obsidians break into knife-sharp chips, harder than steel, and with no cementing value. The vesicular rocks are of light weight and great porosity. Under traffic, they beat down into a dust which is irritating when dry, and, especially in basic varieties, very sticky and red when wet. They are used, however, in certain volcanic regions for road metal.

The Rhyolite-Granite Family (Sp. Gr. 2.50 to 2.60). RHYOLITE FELSITES and PORPHYRIES are usually light colored massive rocks. The ground-mass is usually too fine grained to analyse with the naked eye, but phenocrysts of orthoclase and quartz are commonly present. The ferro-magnesian minerals are generally few and small, with biotite commoner than hornblende. When quartz and orthoclase phenocrysts are abundant, the rock is called quartz porphyry (see Fig. 11). Weathering: Fresh rock is very resistant to weathering. Yields kaolin and quartz stained with iron oxides. Occurrence: Common in the mountainous West, the Black Hills, Yellowstone Park, Leadville, Colo. Rhyolite tuffs are quarried for building stone along the Front Range of Colorado.

Granites (Sp. Gr. 2.55 to 2.86) are the commonest of the igneous rocks. They are usually evenly and equally crystalline. The crystals are quite shapeless because of mutual interference while forming from the magma. Often the larger orthoclase crystals approach a definite shape, and then the rock is porphyritic. If the magma was fairly motionless during crystallization, the crystals fit themselves into each other in an interlocking dovetailed structure (see Fig. 10). The quartz is the last mineral to crystallize, and so assumes the most shapeless form of all, filling the interstices between the other crystals, and binding the mass together. Sometimes there is movement of the magma during closing phases of crystallization. This streaming produces a banded appearance like gneiss. The mica and hornblende in such a rock tends to lie in sheets. The crystals do not interlock so perfectly (see Fig. 13). The strength of a granite depends more upon the degree of interlocking than upon the qualities of the minerals contained. A granite like Fig. 13 Westchester


Fig. 13. Granite, Poorly Interlocked and Gneissoid

Granite, N. Y., or Yonkers Gneiss, N. Y., would be quite unfit for paving blocks or macadam, tho selected material is good for building purposes. Streaks of pegmatites are common in the granite of some regions. Rock of this type is usually rejected for building purposes. Biotite is the commonest dark mineral. Hornblende increases in the darker gray granites. Muscovite is common in the lighter colored varieties. Small amounts of the micas do no harm, but the rock is weakened structurally by larger amounts, or by the arrangement of the micas into layers or laminae in gneissoid varieties. Weathering: Quartz expands and contracts under temperature changes twice as much as does orthoclase. The sutures of a poorly interlocked rock will open up and admit water whose freezing aids disintegration. Orthoclase is softer than quartz, so that under abrasion the rock keeps a rough surface. Orthoclase alters readily to kaolin or clay. Only fresh unaltered granite should be used. Occurs in large masses, stocks and batholiths. See Art. 19.

Pegmatites are usually dikes of giant granite. Escaping solutions from the great magmatic bodies penetrate the country rock and there precipitate the mineral matter brought up in solution, forming quite the largest crystals known in igneous rocks. These masses are well interlocked, but the cleavage of the large crystal masses renders them too weak structurally to be of use. Occasionally they are used for concrete aggregate, in regions of unsuitable rocks. This is done at Waterbury, Conn., by excluding the very micaceous parts of the dike. Occurrence: Common in ancient crystalline metamorphic regions, such as the older Appalachian Province and the New England Highland, and the old crystallines of the far West.

Trachyte-Syenite Family (Sp. Gr. 2.27 to 2.65). These rocks are rather unusual so that the highway engineer has little cause for studying them. The typical trachytes resemble the rhyolites, but lack free quartz. Orthoclase is dominant, often composing almost the entire rock. These are the most acid trachytes known; SiO_2, 65%. With increase in hornblende and pyroxene, they grade toward rocks as basic as the basalts, and as dark in color. Weathering: As in all porphyritic rocks, the phenocrysts sometimes weather before the ground-mass shows much alteration. Usually both alter together. More kaolin and less quartz result from weathering than is the case with the rhyolites. Occurrence: As surface flows, trachytes occur in the Black Hills, Custer County, Colo., and Crazy Mountains, Mont.

The Syenites resemble the granites, but are somewhat more friable, lacking quartz. Orthoclase is dominant, but acid plagioclase is almost always present. With increase of plagioclase, the syenites grade into the diorites. Hornblende is the most common dark mineral, but biotite is also often present. Pyroxene appears in the darker varieties, but pyroxene-rich syenites are rare. Unweathered syenite with well interlocked crystals makes excellent structural material, concrete aggregate and good macadam; less favorable for paving blocks. Weathering: Feldspars alter to kaolin, hornblende to chlorite, but weathering is slow if the quarried rock is fresh. Occurrence: A large boss near Montreal, Canada, and large dikes and knobs near Little Rock, Ark. The Highwood Mountains, Montana, yield the most notable examples, but many smaller dikes are known.

Dacite-Quartz-Diorite Family (Sp. Gr. 2.50 to 2.60). The dacites resemble the rhyolites, except that the plagioclase is the dominant, often the only, feldspar. More biotite and hornblende are usually developed than in the rhyolites. The identification of the rock depends upon the determination of the feldspar, and this is only possible if phenocrysts are present. Texture is felsitic to porphyritic, often cellular in surface flows. In their weathering qualities and suitability for engineering work the dacites resemble the rhyloites (see Art. 6). Occurrence: As flows and dikes in the Cordilleran region and South America.

Quartz Diorites closely resemble the granites, into which they grade with the increase of orthoclase. Plagioclase is dominant. Hornblende and biotite are the commonest dark minerals. The texture is granitoid, and the rocks behave like granites for all practical purposes. Occurrence: In the Cortlandt Series near Peekskill, N. Y.; many localities in the New England Highland, in Yellowstone Park and the Sierras. Far less common than granites.

Andesite-Diorite Family (Sp. Gr. 2.60 to 2.90). The andesites proper are surface flows, cellular or massive, and felsitic. Unless phenocrysts are present, it is often impossible to tell them from trachytes, into which they grade with increase of orthoclase, but they usually contain more dark minerals than the felsitic rocks hitherto described. The absence of quartz and the dominance of plagioclase serve to identify them. Hornblende is the commonest dark mineral but biotite is abundant. Pyroxene appears in the more basic varieties, and by its increase the andesites grade into augite-andesites, or trap. The entire ground mass is often made of small but visible interlocking rods of plagioclase and hornblende or pyroxene. Phenocrysts of hornblende in long shining black rods, and large phenocrysts of gray plagioclase are common. Porphyritic varieties are usually dike rocks. As coarseness of grain increases, the andesites pass insensibly into the diorites. Strength: Massive varieties are tough and hard if unweathered, and are excellent rocks for macadam and concrete aggregate. Weathering: The hornblende alters to chlorite, the plagioclase to kaolin, and both alterations yield secondary silica, and calcite. Under traffic good cementing qualities are developed. Occurrence: Yellowstone Park; many peaks in Colorado, Mt. Hood, Mt. Shasta, and other great cones of the Cascade Range; many other parts of the mountainous West.

Diorites are granitoid-textured rocks, whose chief feldspar is plagioclase, and whose chief dark mineral is hornblende or biotite or both. By addition of orthoclase they grade into syenites, but their closest relatives are the GABBROS, from which they differ in having (1) usually a lighter colored, more acid plagioclase, and (2) hornblende instead of pyroxene; but every intermediate composition occurs, from typical diorites to typical gabbros. It is often extremely difficult to distinguish them in hand specimens, as hornblende is hard to tell from augite. Strength: When well interlocked and fresh, diorites are extremely tough and durable gray speckled rocks, and are sold under the name of granite. They are as ill suited as syenites for paving blocks, but for macadam, concrete aggregate and structural material they are well suited. Quarry conditions are similar to those of granites (see Art. 19), altho the rock quality is often more variable. Weathering: The feldspars kaolinize, and the hornblende changes to chlorite, but the two minerals rarely alter at the same rate. The rock is ruined when either chief constituent decays. Usually the hornblende alters first, but often the reverse occurs. It is impossible to determine beforehand which mineral will weather more, except by examining weathered outcrops. Calcite and secondary silica are further products of decay, furnishing bond. Occurrence: As large intrusive bodies, sheets or stocks, often associated with gabbros. In the Cortlandt Series, New York; Mt. Davidson, Nevada.

The Augite-Andesite-Gabbro Family may be treated for brevity's sake with the BASALT-OLIVINE-GABBRO group. The rocks differ chiefly in the presence or absence of olivine. They often occur associated together, even in the same intrusive mass. Unless the olivine crystals are visible, it is often impossible to distinguish the fine grained varieties without the microscope. Surface flows of BASALT (Sp. Gr. 3.01) are usually vesicular if thin, but thick flows are commonly very dense except near the upper surface, where the escaping gases fill them with bubbles, and make a scoriaceous zone. The low melting point of these rocks enables them to freeze so slowly that the magma can crystallize even when a surface flow. Glassy texture is seldom seen except as crusts upon flows, or as scoria. Olivine, if present, is one of the first minerals to crystallize, and its green glassy phenocrysts,

usually shapeless, are easily recognized, even in felsitic basalts. It alters readily to serpentine, a dull green earthy or fibrous mass. The felsitic types are sometimes mistaken for black limestone in hand specimens. Basalt is heavier and far harder than limestone, which can be easily cut with a knife, and besides, basalt usually shows a few typical igneous phenocrysts, olivine, plagioclase or augite. The plagioclase often crystallizes while the rest of the rock remains liquid, and thus attains perfect crystal form. These plagioclase crystals are long lath-shaped rods, which lie unoriented, in every possible position. The pyroxene, and olivine, if present, crystallise later, and form shapeless crystals filling in the space among the feldspar rods. The whole rock is therefore something like concrete in structure, but the crisscrossed interlacing rods of plagioclase involved in the pyroxene which is almost as hard as steel gives unusual strength to the mass. Such a structure is called DIABASIC. See Fig. 14. A represents plagioclase; B, pyroxene; C, olivine; the black is magnetite. Diabasic rocks (Sp. Gr. 2.60 to 3.03) may have the composition of a basic diorite, with much hornblende present, or of a gabbro, or of an olivine gabbro. Their crystals may be so small that the rocks are felsitic, or as large as an inch in length. The finer grained diabases are the strongest, and are those used under the name of trap.

Fig. 14. Diabase

Gabbros differ from diabases in having the even granular texture of normal granitoid rocks. It is impossible to give a description to cover them, for they are the most variable of igneous rocks. Almost any one of their minerals may in varieties be the principal constituent of the rock. Increase of plagioclase brings a variety that is almost pure, gray labradorite plagioclase. Great areas of this rock are found in eastern Canada and the Adirondacks; smaller masses occur near Lake Superior in Minnesota, and in the Laramie Mountains, Wyoming. With increase of pyroxene, to the practical exclusion of plagioclase, the gabbros grade into the pyroxenites. The peridotites represent an olivine-rich extreme variety. The recognition of a gabbro must depend upon the naming of the component minerals. The plagioclase, when present, is always basic, usually gray in color. The dark minerals are essentially pyroxenes with or without olivine. Biotite is common, and hornblende not rare.

Strength: When fresh, well interlocked, and not too coarsely crystalline, the gabbros are satisfactory for all road-building purposes. The diabasic varieties called trap are among the best of metals for heavy traffic roads, but are to be avoided, as a rule, for light traffic by-roads. In weathering the pyroxenes and olivine yield serpentine, which in turn breaks down into soluble and cementing materials, magnesite, limonite, calcite, secondary silica. The plagioclases yield carbonates and kaolin, and secondary silica. Thus the cementing power of the gabbro group is very high. Varieties too high in olivine are to be avoided, but the best types are also the commonest. Occurence: In dikes, large sills and large intrusive masses. Even large surface flows may be diabasic in their central portions, as in the Orange Mountains of New Jersey, or the great surface flows of the Connecticut Valley. The surface flows and sills crack into vertical columns as they cool, for the cooling surfaces are the top and bottom faces of the sheet. This vertical jointing causes the rock masses to develop nearly vertical cliffs, often showing a fluted, columnar structure, well displayed in the basalts of the Columbia River Plateau, the trap sheets of New Jersey, of Cape Blomidon in Nova Scotia, and a host of other occurrences. The vertical cleavage is supplemented by a horizontal system of joints, which often curve and intersect

one another, splitting the rock into horizontal lens-like masses. Quarrying is thus rendered comparatively easy, and the rock can be obtained in sizes convenient for the crusher, but not, as a rule, in good dimension blocks. Olivine, crystallizing early in the liquid magma, may sink thru the liquid, and come to rest in a layer or zone of concentrated olivine crystals near the bottom of the intrusive body. Because olivine alters so readily to serpentine, this part of the rock is weak, and must be avoided in quarrying. Gabbros form the central mass of the Adirondacks, and occur along Lake Superior, in the Cortlandt Series near Peekskill, N. Y., and near Baltimore. Patches are known in the New England Highland. Basalt and diabase are far more common than gabbro proper. The Triassic traps include a series of isolated patches on the eastern shore of the Bay of Fundy, Cape Blomidon, in the Connecticut Valley, the Palisades and Watchung Mountains, in eastern New Jersey, at Cornwall, Pa., Richmond, Va., and Deep River, N. C. (Art. 14, Fig. 51, black areas), around Lake Superior, especially on Keweenaw Point, and Thunder Bay. The vast basalt-lava flows which form the Columbia River Plateaus are among the greatest in the world. See Art. 14.

3. Sedimentary Rocks

Composition: Sediments are (1) fragments of other rocks, broken apart by weathering, (2) precipitates from solution, (3) the remains of the hard parts of animals and plants, or (4) any mixture of the first three classes. Most sediments contain two distinct and essential elements: (1) The grains or particles which give the rock its name; and, (2) the cement or binder that holds the particles together.

The GRAINS are of three types: (1) They may be fragments of pre-existing rocks of any type. See Arts. 2 and 6. The decomposed products of the weathering of other rocks may be transported by wind, streams, waves or glaciers, or any combination of these agents. The smaller grains are usually sorted out from the larger, and the size of grain that comes to rest in a given place is apt to be uniform, according to the strength of the transporting agent at that place. See Art. 11. The dominant minerals are: Clay, kaolin, in the finest grained rocks; quartz and feldspar in the coarser sediments. Minor materials are hornblende, biotite, muscovite and comminuted limestone. (2) The grains may be shells or their fragments, including corals. Nearly all groups of waterliving organisms, plant and animal, contribute to these deposits. With these may be mingled clay and sand derived from the land. (3) Precipitated rocks need not be considered in a book for engineers. Gypsum and salt deposits are the commonest examples.

The BINDER OR CEMENT: Too much emphasis cannot be laid upon the importance of the binder. The strength of the rock depends wholly upon how it is bound. The weak St. Peter sandstone, made of resistant quartz grains, almost lacks a binder. Bluestone, made of weaker grains, well bound, is one of the strongest of rocks. The binder may be one of three types: (1) It may be part of the sediment. Clay and iron oxide deposited with the larger grains may form a strong cement under suitable pressure. This is the case with many brownstones, tho carbonates and silica play a part. (2) It may be introduced matter, brought into the sediment by percolating waters, and precipitated. Lime carbonate, silica and iron carbonate are the commonest examples. Silica usually precipitates as quartz. In sandstones, this quartz is built upon the primary quartz grains, enlarging them until they meet each other and form an interlocking crystalline mass, like an igneous rock. The strong Potsdam quartsite is of this type. Lime carbonate crystallizes very readily in the interstices of the sediments, and is a strong, but soluble binder. Any mixture of binders may occur. (3) The

binder may be wholly internal, produced by a chemical reorganization of the sediment, by which some cement is set free. The binder of limestones is largely derived from the sediment itself, by solution and recrystallization of lime carbonate. Type 3 may to some extent accompany types 1 and 2.

Classification of Sedimentary Rocks: Sediments are classified according to texture, composition and mode of origin. Rocks precipitated from aqueous solutions are called HYDROGENIC; salt, gypsum and some limestones. Rocks produced by living organisms are called BIOGENIC. These are chalk, infusorial earth, coal, most limestones, etc. Rocks produced by igneous activity are called PYROGENIC. The igneous rocks are the ultimate source of all sediments. Any of these rocks may be broken into fragments by weathering processes or by dynamic force. The fragmental materials constitute the great bulk of sediments, called the CLASTICS. The clastics, however derived, may be classified as shown in Table IV.

Table IV.—The Clastic Sedimentary Rocks

UNCONSOLIDATED SEDIMENTS

Coarse, Angular	Coarse, Worn	Medium	Fine	Very Fine
Talus, and landslide materials Volcanic fragments, Fault crush zones	Gravel Clay-galls Coral and shell deposits	Quartz sands Arkosic sands Lime-sands	Silt, fine and clayey sands Clay, + carbonate mixture	Rock flour, Volcanic dust, Loess Clay, Marl, and lime muds

CEMENTED OR INDURATED, FORMING ROCK

Coarse, Angular	Coarse, Worn	Medium	Fine	Very Fine
Talus breccias Volcanic breccias Fault breccias	Conglomerates (various) Quartz conglomerates Coquina, Coral rag	Sandstones, Arkoses, Bluestones Lime sandrock	Silicious shales, Fine grits, Shaly sandstones, Sandy and clayey limestones	Various fine grained and shaly rocks Clay shale Marl, lime mudrock

Conglomerates are little used, except occasionally as building stone. When the pebbles are quartz with silicious binding, the rock is very strong and hard to quarry or dress. It may break along joints and bedding planes into usable blocks. The pebbles may be of any material, limestone, shale, granite grains, feldspar, etc, and the binder may vary extremely, both in quality and amount. When the binder does not fill up the interstices between the pebbles, the rock is very porous, and may hold great amounts of ground water. Sand grains are often mingled with the pebbles, and help to eliminate pore space.

In Sandstones (Sp. Gr. 2.00 to 2.78) the grains are commonly quartz, often with some feldspar. When the feldspar grains are abundant, the rock is called

arkose. The familiar brownstones of Connecticut, New Jersey and Pennsylvania are arkoses. Mica flakes are common, and the rock splits easily along beds where mica is abundant. Clay is often present, especially in fine grained sandstones. Such rocks are usually thin bedded, grading into shale. In marine sandstones the fossil shells are very common. The lime carbonate of these has often leached out, leaving cavities that may seriously weaken the rock. The thickness of the bed limits the size of the blocks that can be extracted, some beds being 4 ft thick, but a 1-ft bed is usually called thick. Cross-bedding (see Fig. 15) is very common, and is sometimes called false bedding. When cross-bedding is prominent, the rock may weather out and split along these slanting planes, and so be unfit for use. The degree of weakness will depend largely upon the character of binder present.

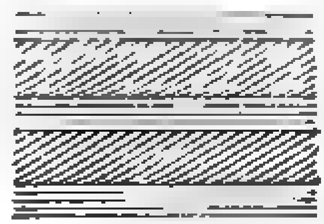


Fig. 15. Cross-Bedding

Fig. 16. Potsdam Quartzite

Quartzite (Sp. Gr. 2.60 to 2.70) is a sandstone with quartz grains, and a binder of precipitated silica. The silica builds itself on to the primary grains, enlarging them until they meet and interlock firmly. Fig. 16 shows the Potsdam sandstone, a typical quartzite, with interlocking, secondary silica filling interstices. The rock is nearly as strong as granite. It quarries in flat blocks, favorable for masonry. It makes very poor macadam, as it is hard and brittle, with very low cementing power. The name quartzite is also applied to a strictly metamorphic rock, which for practical purposes behaves like the type here described.

Bluestone is a gray, green, bluish or purplish bedded rock consisting of granular fragments of older metamorphic rocks, such as slates, with less quartz, and occasional feldspar grains. In the interstices, clayey matter and silica have recrystallized into a fine dense aggregate of quartz and flaky sericite and chlorite. Pore space is thus greatly reduced, and all the grains slightly enlarged by addition of silica to their surfaces, so that they form a firmly interlocking mass, almost as strong as a granite. Bluestone resists weathering and abrasion, is very tough, and has good cementing value. It quarries in flat slabs usable for flag, curbs or building stone, according to thickness. The coarser grained varieties are the strongest, as the finer grained rock contains clay. Some bedding planes in the rock are rich in platy biotite and hornblende. These planes look darker, and are lines of weakness along which the rock may be split. They are called reeds (see Fig. 17, AA). See also Art. 19. Pebbles of quartz do not seriously injure the bed, but little balls of clay, claygalls, are often present, and these weather out readily. Rock containing them should not be used, except for light traffic macadam.

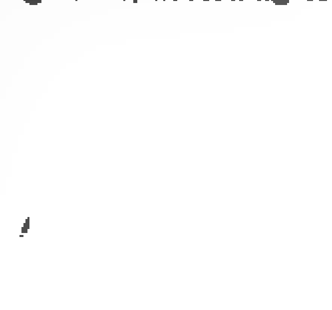


Fig. 17. Bluestone, AA, Reed

A kind of sandstone is made when igneous fragmentals, volcanic ash beds, become cemented together. These rocks are extremely variable as to both texture and structure. The commonest binder is calcite. They are quarried for building stones on the Colorado Front Range, and elsewhere in the West. Most sandstones are porous either because of original voids, not filled by cement, or because of the leaching out of the soluble binder or grains. In Fig. 11, grains are shaded, cement is black, and voids or pores are white. Sand-

stones form great reservoirs of underground water, and when working in sedimentary rock regions, the engineer must carefully look for seepages among sandstone beds. Bluestone and quartzite usually have the least porosity.

Shale (Sp. Gr. 2.40 to 2.80) is typically a clay rock that cleaves readily parallel to the bedding. Sand and lime carbonate are almost always present. With increase of either, the rock grades into shaly sandstone or shaly limestone. Iron salts and magnesium carbonate are common impurities. Shale weathers into clay with impurities as noted. It makes a poor macadam, but silicious varieties are much used for light traffic roads. Clay shales with little lime present are often used in brickmaking; never for concrete aggregate.

Limestones (Sp. Gr. 2.35 to 2.87) are extremely variable. Their composition may be nearly pure calcium carbonate. Magnesium carbonate, which is nearly always present, may increase to practically the exclusion of $CaCO_3$, but usually not beyond the proportions for dolomite, with $MgCO_3$, 45.65%. Clay and silica are almost never absent; either or both may increase to such notable amount that the rock grades into shale and sandstone. Silica may appear as sand grains, or as flint or chert in nodules or irregular streaks up to 1 ft in length. Other common impurities are iron carbonate and sulphides, carbonaceous matter and gypsum. The GRAINS may be particles of structureless lime mud or minute shells; larger shells, corals, etc, or their fragments; pebbles of limestone; grains, crystals and masses of all the impurities named. The CEMENT is almost always calcite. Texture varies from fine grained dense mud rocks in thin or thick beds; thin granular sand lime rocks, dense or porous, usually made of fossil fragments; to coarse clastics, such as shell rocks, coral rag, or conglomerate made of limestone pebbles.

Structure. Clay bearing varieties are usually shaly. Beds range to several feet in thickness, often very regularly bedded and jointed. Chert in small streaks does not prevent easy quarrying for masonry, but large chert masses cause irregularities in bedding and in weathering qualities. Percolating waters often dissolve limestones, forming caverns of extremely variable shapes and sizes. See Art. 12. Hard, dense limestones are good rocks for all purposes, except macadam for very heavy traffic roads. They have fair toughness, rather low hardness, and excellent cementing qualities. Cherty limestone makes good road metal, the hard flint with low cementing qualities being bonded by the limestone. Structures under water should not be built of limestone, nor should limestone aggregate be used in concrete exposed to either running water or ground water, because of the ready solubility of the rock.

4. Metamorphic Rocks

Metamorphic rocks include the slates, schists, gneisses, serpentines and marbles.

Slate (Sp. Gr. 2.50 to 2.80) is a strongly cleaved, fine grained rock, derived from shale, thru the agency of great pressure, at considerable depth below the surface. The shale tended to deform slowly under the stress, and to develop a very perfect cleavage at right angles to the direction of the stress (see Fig. 18). The clay material was in part recrystallized to form minute mica flakes, all lying parallel to the slaty cleavage. The cleavage is not at all related to the original bedding of the shale. Slates are fairly hard and tough. They are used to make light traffic macadam. They pack well, and have good cementing qualities, but ultimately yield much mud and dust. Slate is useless for any other road making purpose. Shales, slates, clayey sandstones,

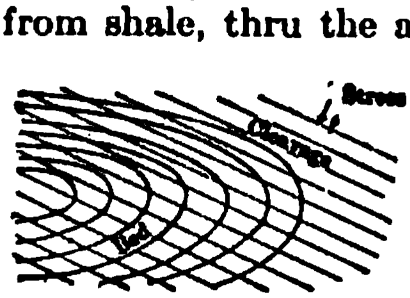


Fig. 18. Slaty Cleavage

shaly limestones and fine grained igneous rocks will, under great pressure and heat, recrystallize into schist of many varieties.

Schists are more thoroly crystallized than slates, and their crystals are usually visible. They consist chiefly of cleavable minerals, mica, hornblende, or chlorite, lying with their prominent cleavages parallel, giving the rock a fine cleavage or foliation called SCHISTOSITY. Granular quartz and feldspar are present in variable amounts. When garnet and staurolite are developed, they never lie in parallel sheets, but are scattered quite independently of the rock cleavage. Schists when fresh and firm are sometimes used as structural material. They must never be set on edge, but must be laid with the planes of schistosity horizontal. Schists, in weathering, tend to split into flat sheets, as well as to disintegrate into grains and flakes. They are not to be used for aggregate, macadam or paving blocks.

Gneiss (Sp. Gr. 2.62 to 2.92) is coarse grained, thoroly crystalline, contains much feldspar, and is streaked or banded, due to the parallel arrangement of the mica and hornblende. Differs from schist in that it usually has coarser grains, greater feldspar content, and less perfect cleavage. The commonest gneisses resemble granites in their texture and composition, but gneisses may be derived from any coarse grained, feldspathic rock, sedimentary or igneous. The feldspar and quartz are often granulated, due to crushing pressures during metamorphism. The parallel streaks of cleavable minerals are not always planes of weakness. Gneisses are often excellent structural material, and the stronger varieties have been used successfully as concrete aggregate, altho the practice is not to be recommended. Gneisses are never used for paving blocks, and should not be used for macadam.

Marble (Sp. Gr. 2.08 to 2.85). Limestones recrystallize under great pressure and heat, to form marble, which is usually a thick bedded, or massive rock, formed of interlocking, shapeless crystals of calcite or calcite and dolomite. Quartz, brown mica, amphiboles, pyroxenes and olivine are often present in variable amounts. The rock makes fairly good structural material, but like other limestones always should be used above the waterline. Fine grained, well interlocked marbles may be used as aggregate or macadam, under conditions similar for those described for limestones.

Serpentine (Sp. Gr. 2.72) is a complex of hydrous silicates, chiefly of Mg and Fe. The mode is roughly as follows: MgO, 38%; FeO and Fe_2O_3, 7%; SiO_2, 41%; H_2O, 12%; variable amounts of Al_2O_3 and CaO. Its color is usually greenish. The rock is always complexly jointed, and the fractures are often slickensided and polished, thus rendering the mass very weak. When the fractures are cemented together by carbonate of magnesia or calcium, the rock may be fairly strong. Fibrous varieties and varieties with a rudely platy cleavage are common. It weathers readily, yielding carbonates or Ca and Mg, with silica, clay and limonite. Thus good bonding qualities, but almost no other good can be expected.

To Estimate the Weight of Stone: (1) In bed rock before quarrying, multiply the specific gravity of the rock by 62.4 lb to find the weight per cu ft, or by 1684.8 to find the weight per cu yd. (2) Crushed stone contains about 35% voids when all sizes are mixed, and from 45 to 48% when screened into separate sizes; sand contains 35 to 40% voids. The following table is quoted from Gillette, see (4):

Table V.—Weights of Rock, Solid and Broken

Sp. Gr.	Weight, Pounds per Cu Yd	Weight in Pounds per Cu Yd when Voids are				
		30%	35%	40%	45%	50%
2.2	3704	2593	2408	2222	2037	1852
2.3	3872	2711	2517	2323	2130	1936
2.4	4041	2828	2626	2424	2222	2020
2.5	4209	2946	2736	2525	2315	2105
2.6	4377	3064	2845	2626	2408	2189
2.7	4546	3182	2955	2727	2500	2273
2.8	4714	3300	3064	2828	2593	2357
2.9	4882	3418	3174	2929	2685	2441
3.0	5051	3536	3283	3030	2778	2526
3.1	5219	3653	3392	3131	2871	2609
3.2	5388	3771	3502	3232	2963	2694
3.3	5556	3889	3611	3333	3056	2778
3.4	5724	4007	3721	3434	3148	2862
3.5	5893	4125	3830	3535	3241	2947

5. Petrographic Methods

Petrographic methods are the most subtle methods yet devised for examining rocks. A small sample of the rock, as firm and sound as can be obtained, is ground on a revolving lap until a thin, flat sliver, polished on both sides is obtained. This is mounted in Canada balsam on a glass slide. The rock slice is so thin that light readily passes thru the minerals. The slide is then examined under a polarizing microscope. Not only can all minerals and their relative proportions be recognized, but the shape of crystals, manner of interlocking, degree of alteration and decay, presence and arrangement of cracks and cleavages, and pores, can all be distinctly seen. A state of internal strain in the rock mass can be detected in polarized light. Defects which neither hand lens study nor standard rock tests will detect, such as a state of internal strain in the rock mass, are revealed. It costs 50 cents to have a rock section cut, and not more than ½ hr to study it. Even in the field, a rock may be polished on one face by holding it to the flat of a grindstone, and afterward smoothing it on an oil stone. Keep the surface wet with oil or water, and study it in a good light with a hand lens. The shape, arrangement, interlocking mineral cleavage, and cementing material, will all show up fairly well.

6. Rock Weathering and Soils

Weathering is the destruction of rock by reason of physical and chemical changes that take place near the surface. Erosion is the removal of rocks or their decayed products by wind, waves, streams, glaciers, gravity, etc. Physical changes involved in weathering are collectively called disintegration. The result of disintegration is simply the breaking down of the solid rock into fragments or grains of its component primary minerals. Chemical changes involved in weathering are collectively called decomposition. The minerals are altered chemically into materials wholly different from the original minerals of the rock. Usually rocks suffer both disintegration and decomposition simultaneously, but disintegration to some extent may precede.

Disintegration. Heat causes some minerals to expand more than others. Hornblende expands more than orthoclase, and quartz more than either. When a rock is composed of several different minerals, heat and cold tend to make them pull apart, and gradually open up minute fractures between the grains. Water enters any crevices in the rock; bedding or schistosity planes, cleavages, cracks of minerals, pores or the crevices caused by temperature changes. If such water freezes, it expands, exerting a force of more than 1 ton per sq in, and so tends to pry the grains apart. The daily heating and cooling of the whole surface of the rock mass causes it to pull away from the interior rock whose temperature remains uniform. In arid regions, vast masses of rock are broken up by scaling-off of the surface. Wind, streams, waves and ice have little abrasive effect upon rocks, but they are usually armed with grains or pebbles which they drag across or drive against rock surfaces, and thus scrape them. This is, of course, a method of erosion. In arid regions, near sand-dunes and along beaches, wind armed with sand grains is a powerful agent of rock destruction. Roots of plants enter crevices in rocks, and growing there, wedge and even lift the rocks apart.

Decomposition. Oxygen, carbon dioxide and moisture in the air attack rocks slowly. Descending ground waters carry these gases in solution, together with sulphuric acid, organic acids, carbon dioxide and salts, all obtained from the soil. All these reagents attack rock minerals. The dominant reactions are called hydration, carbonation, oxidation and solution.

Hydration is the chemical combination of water with mineral matter to form hydrous compounds. Orthoclase takes up water forming kaolinite, and freeing silica and potash. The potash reacts with the CO_2 present. See CARBONATION. Orthoclase, $2KAlSi_3O_8 + 2H_2O + CO_2 =$ Kaolinite, $H_4Al_2Si_2O_9 + K_2CO_3 + 4SiO_2$. The kaolinite is pure clay or clay base. The potassium carbonate is gradually dissolved out. The silica is partly leached out, but may precipitate as quartz, chalcedony, etc. The plagioclases yield kaolin, silica and carbonates of sodium and calcium. Hence the bonding quality in macadam of the lime-bearing basic plagioclases exceeds that of orthoclase and acid plagioclase. Hydration of hornblende and the pyroxenes yields hydrous silicates, chlorite or serpentine or both. Silica is freed, and carbonates are formed. Olivine hydrates rather readily to serpentine. Hydration results in an increase in volume, and the products are always softer than the original mineral.

Carbonation is the union of a base with the CO_3 radical. CO_2 dissolved in water forms H_2CO_3, which attacks silicate minerals, forming carbonates of the contained sodium, potassium, magnesium and iron, and liberating silica. These carbonates are in part removed in solution and in part precipitated. Carbonation increases the original bulk by 15 to 50%. It accompanies hydration.

Oxidation. The assumption of oxygen is practically confined to the iron in minerals. Limonite and hematite are formed. Sulphides of iron, like pyrite, yield upon oxidation, sulphuric acid, which further attacks minerals. Rocks containing much pyrite should be avoided, especially for concrete work.

Solution. Almost all of the products of decomposition are somewhat soluble. Of the oxides forming the common rock minerals, Al_2O_3, Fe_2O_3, SiO_2 yield, in weathering, relatively insoluble compounds. Hence clay, iron oxides and sand are common end-products of rock decay. K_2O, Na_2O, CaO, MgO and FeO yield relatively soluble compounds, which are leached out. Solution thus reduces rock bulk by more than the increase caused by other reactions. Rocks are soluble in proportion as they contain much or little of the soluble-salt-producing oxides. Hence, limestones are very subject to solution.

SOILS

7. Classification of Soils and General Data

Soil in general is the mantle of loose material overlying solid rock. It is the product of disintegration and decomposition. The upper finer grained layer which supports plant life, is mixed with humus derived from

the decaying vegetable matter, and is called the soil proper. The SUBSOIL underlies the soil, and is the less thoroly weathered part, which does not contribute much to the support of plant life, and generally contains no organic matter.

Sedentary and Transported Soils. Soil which remains exactly in the same position in which it first formed, is called sedentary soil; and soil which is removed by erosion, and deposited in some other place is called transported soil. These are subdivided by Merrill (10) as follows:

Sedentary Soils	Residual: Residuary gravels, sands, clays, etc.
	Cumulose: Peat, muck, and swamp soils in part.
Transported Soils	Colluvial: Talus and cliff debris, avalanche material.
	Alluvial: Modern alluvium, marsh and swamp deposits.
	Aeolian: Wind-blown material, sand-dunes, adobe and loess in part.
	Glacial: Morainal material, drumlins, eskers, etc.

A Residuary Soil may be recognized by the following criteria: (1) It is of finest grain at the top, and becomes increasingly stony downward, until it passes gradually thru mixtures of rock and soil into bed-rock; (2) it contains pebbles or fragments of the bed-rock only; (3) it is chemically and mineralogically akin to the bed-rock, since all its constituents have been derived directly from that bed-rock, except what is contributed by decaying organisms. See Fig. 19.

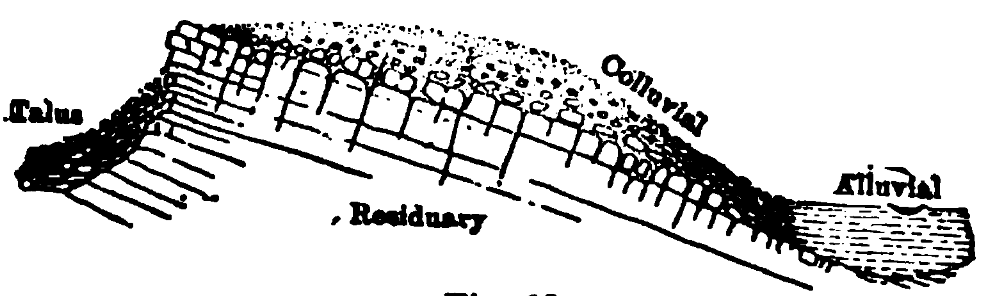


Fig. 19

Within the glaciated area, residuary soils are rare, because the glacier stripped off the weathered matter in its path. South of the glaciated area, residuary soils are dominant. Feldspathic igneous rocks yield heavy clay soils, yellow to red, with varying percentages of iron and silica content. The basic igneous rocks yield lighter soils of dark color, high in iron, lime and phosphates; their variable clay content is derived from all the aluminous minerals, feldspars, amphiboles and pyroxenes.

Gneisses give soils resembling those of corresponding igneous rocks. Mica-schists yield lean, sandy, micaceous soils. Hornblende and chlorite-schists give soils like those of the basic igneous rocks. Conglomerates disintegrate to form gravels, if their pebbles are of resistant material. Sandstones yield lean, light sandy soils, increasing in clay in arkosic varieties. Shales weather into heavy clay soils. See Art. 8, CLAY.

Limestones very commonly carry clay or silica, or both, as impurities (see Art. 3), and so yield variable mixtures of these materials when the lime carbonate dissolves out; usually a rich, fertile soil, but often forming especially tenacious muds, like the gumbo-muds of the Black Prairies, Alabama to Texas. Many such clays slake and crumble upon drying, so that in the road they are objectionable whether dry or wet.

Colluvial Soil. All creep and wash material on hillsides (see Fig. 19) are called colluvial soils when they have moved far enough from their positions as residuary soil to mix with material derived from other strata (see Art. 8). In this sense they are very widespread and composed of soil mingled with rock fragments of as many kinds as there are different formations in the hill. Because the finest materials were originally on top, and because the finest particles are easiest to move, the hillside may become covered with a continuous layer of clay, altho only part of the bed-rock yields clay soil. This fact is of importance in estimating the possible clay

content of a hill and in conditioning ground water movements (see Art. 12). Talus slopes are colluvial soils at the foot of cliffs (see Fig. 19). They consist of angular fragments of the cliff rock, ranging from small pebbles to great blocks. The upper part is steeper and rockier than the lower slopes, where long weathering and creep movements have often covered the slope with soil. The base of the slope is very often the locus of many springs and marked seepages, while the higher parts are porous and dry. Landslide and avalanche material are composed of soil and rock, or of rock alone. All colluvial soils are subject to slide movements. See Art. 13, for definition and discussion of creep, slides, etc. Talus slopes can be recognized by their form, a steep concave slope of 30° to 40° at the foot of a cliff. Hillside colluvial soils are expectable on any hill slope, and can be recognized in a section by their confused commingled character, in contrast to the orderly gradations of residuary soils; also by surface evidences of slumping and creep. In the stream valleys, the colluvial soils abut against or sometimes grade into alluvial, stream carried soils.

Alluvial Soils are the flood-plain and delta deposits of rivers, and the alluvial cones built by mountain streams emerging into the plain. See Art. 11.

Aeolian or wind-blown soils include dune sand and part of the loess, and are common in the Mississippi Valley. Dunes are hills of blown sand, found along beaches and in arid sections. The wind often blows the sand from one side of the dune and drops it on the other, so that the whole dune moves slowly forward. Highways and railroads are sometimes buried under the moving dunes. They can sometimes be fixed by planting them with suitable grasses.

Loess is a fine grained very compact soil of clay, silica and carbonate particles, part wind-blown, part water-laid, that formed in the Mississippi Valley, central Europe, Russia and China, during or just after the glacial period. It may be considered a clay for the highway engineer's purposes. It is recognized by its invariable surface position, its definite geographical distribution, its uniform fine grain and great compactness, so that it forms vertical cliffs when trenched by streams. Its depth varies from 8 to over 150 ft in the Mississippi Valley.

8. Special Soil Types

Definitions. Light soils are soils found easy to plough, not necessarily light in color or weight. Heavy soils are tough, tenacious clay soils difficult to plough. The term does not refer to specific gravity. Hardpan means either, (1) a very dense subsoil, such as tough clay, or (2) a cemented layer in the soil, where ground waters have precipitated a local binder of silica, carbonates, iron oxides, etc, or (3) dense, clayey glacial drift. Humus is the carbonaceous matter produced by decaying organisms. Mold is the light spongy humus resulting from the decay of leaves, etc, in forests. Muck is a fine grained, usually black matter found in swamps, and consists of fine transported silts mingled with much carbonaceous matter from decaying vegetation; muck also means soft silt spread out by an overflowing river upon its flood-plain. Loam is a sandy or clayey soil mixed with humus. Silt consists of naturally deposited mineral particles that may lack the colloidal qualities, plasticity, etc, of clay, but are too fine grained to class as sand. Silt will pass a 200-mesh sieve. It usually contains much clay, and generally need not be distinguished from clay. Silt is found in the flood-plain deposits of large slow rivers, and in their deltas, the clay content being largely washed out and carried further, but the silt yields clay upon weathering.

Sand and Gravel. There is no scientific basis for a line of demarcation

between sand and gravel, or between sand and silt. Gravel consists of pebbles, generally more or less rounded, either of mineral or rock fragments. The commonest mineral pebble is of quartz. But pebbles of granite, gneiss, quartzite, chert, sandstone, limestone, slate, shale, etc, occur abundantly under suitable conditions. Similarly, sands are known whose grains are gypsum, coral shell or limestone particles; magnetite, garnet and other hard and heavy minerals; rock fragments, which are themselves of complex mineral composition.

The dividing line between sand and gravel must be drawn on a basis of size of grain. The U. S. Bureau of Soils has adopted the following sizes: Fine gravel, 2 to 1 mm (0.08 to 0.04 in); sand, 1 to 0.05 mm (0.04 to 0.002 in); clay below 0.005 mm (0.002 in). In 1915 the Special Committee on "Materials for Road Construction" of the Am. Soc. C. E. and Committee D-4 "Standard Tests for Road Materials" of the Am. Soc. Test. Mat. advocated the adoption of the following basis for differentiation between gravel, sand, silt and clay: Gravel, particles retained on a 10-mesh sieve, standard Am. Soc. Test. Mat. opening 1.85 mm (0.073 in); sand, particles passing a 10-mesh sieve and retained on a 200-mesh sieve, standard Am. Soc. Test. Mat. opening 0.0673 mm (0.00265 in); silt or clay, particles passing a 200-mesh sieve.

Clay is not a mineral, but a very fine grained, usually plastic mud; a mixture of particles of many different minerals in various stages of decomposition. Clay base, pure clay or kaolinite, $H_4Al_2Si_2O_9$, is the mineral that gives plasticity to the mixture, but pure clays are very rare. Sand, lime carbonate, magnesium carbonate, dolomite, siderite (iron carbonate), and limonite (iron hydroxide), are the commonest impurities, but feldspar, mica flakes, hornblende, pyrite, gypsum and marcasite and their decomposition products may be present in varying proportions.

Kaolinite contains SiO_2, 46.50%; Al_2O_3, 39.57% H_2O, 13.93%. The nearer a clay approaches this composition, the more refractory and lighter colored it becomes. CaO, K_2O, Na_2O, FeO and MgO act as fluxes, lowering the temperatures of incipient vitrification. If their sum exceeds 10% of the clay, the mixture is too fusible to use as brick. Ries (12b) gives the following extremes and averages for the content of the more variable ingredients in brick-clays.

	Minimum	Maximum	Average
Silica	34.350	90.887	39.270
Ferric Oxide	0.126	32.120	5.310
Lime	0.024	15.380	1.518
Magnesia	0.020	7.290	1.052
Alkalies	0.170	15.320	2.768

Testing of Clays. In the field, the plasticity may be roughly determined by molding wet clay with the fingers. Experience enables one to form reliable judgments by this means. Presence of coarse sand is shown by pulverizing dry clay with the fingers and feeling the hard sand grains. To detect fine sand, a little clay is taken in the mouth, and the grit is easily felt with the teeth. Any weak acid added to dry clay will cause effervescence if much calcium carbonate is present. Red, gray or green color is probably due to iron, but gray and black usually suggest carbon as well. Sulphides are often detected by their brassy color when the clay is rubbed to powder, and studied thru a hand-lens. The smell of burning sulphur is noted when a sulphide-bearing clay is rubbed briskly between two pieces of steel. The presence of concretions or clay-dogs and clay-ironstone must be carefully looked for if the clay is to be

used for brick. A concretionary or a pebbly clay generally should be rejected. Better material is almost always available by looking farther. Finer tests are made in the laboratory by subjecting samples of the clay to physical tests and by burning samples in kilns. Samples from different parts of a given clay bank should be used, to test the uniformity as well as the quality of the clay. The practical tests are better than chemical analyses. Many valuable clays are not plastic, but those with good bonding qualities are of value for roads, brick and tile. Eckel calculates that clays weigh from 96 to 135.4 lb per cu ft, a fair average being 120 lb for clay in the bank.

Clays are Classed as (1) residuary, and (2) transported clays. Residuary clays result from the weathering of any rock bearing clay or aluminous minerals, such as feldspar, hornblende, pyroxenes and micas. The general character of the clays resulting from various rock types have been stated in Art. 7.

Occurrence and Recognition of Clay Deposits. Residuary clays are not stratified, and are apt to be of limited extent, and to become more rocky downward, grading into bed-rock. This is not always true. Limestones often end rather sharply against their overlying residuary clays, tho a belt of rotten limestone usually forms a transition zone. Clays may grade downward into usable shales; clays of the Atlantic Coastal Plain are often themselves the bed-rock. The depth of all residuary clays deposits is variable and the character changes with depth. Exploration with the ground auger or by test pits is necessary. Outcrops of shale on hillsides weather readily, giving a soft, slippery slope covered with clay and shale chips, while harder rocks like sandstones stand out as ridges. The down-slumping of weathered clay may hide the outcrop of other rocks lower down, suggesting the presence of more shale than is actually present. The dip and strike of every outcrop should be plotted, and a structural cross-section of the hill drawn. The shales will probably have the same dip as the sandstones and limestones. If the cross-section shows clay beds of workable thickness, these should be carefully explored by means of test pits or borings, for the shale may have sandstone or limestone partings that would render it unworkable for brick clay.

Transported Clays. Within the glaciated region (see Art. 14, Fig. 68) transported clays are found in drumlins, boulder clay, or till, glacial lake deposits, and the clay terraces along rivers. Drumlins may be at once recognized by their form (see Art. 9, GLACIAL DEPOSITS). They have been opened for road material but not for brick. Till is much used for roadway earth and fill but never for brick. Clay terraces and lake deposits furnish enormous masses of brick clay. Any hill-enclosed, broad, flat area within the glaciated region may be examined for clay. The centers of such deposits, out from the former lake shores, are more apt to carry clay, the borders being sand and gravel. A layer of sand often overlies the clay. Clay terraces (see Fig. 20) are found along many rivers, especially within the glaciated region or along streams continuing southward away from the glaciated area, or along northward flowing tributaries of glaciated streams. For their mode of origin see Art. 9, GLACIAL DEPOSITS, and Art. 11. Some terraces are of sand and gravel, and the clay terraces may contain streaks of coarse sediment. If a terrace proves to be gravel, terraces of the same elevation will probably be gravel also. The same holds true of clay. To explore a brick-clay prospect, borings or test pits should be put down along lines laid out 50 to 100 ft apart, and the vertical section

Fig. 20. River Terraces

in each hole plotted to scale along a natural profile, so that series of detailed sections are constructed. Shale outcrops and clay terraces are very favorable deposits to work because their quarries are easily drained. If sand or gravel underlies the clay, the quarry is sometimes drained by digging wells thru to the porous bed.

9. Glacial Drift and Swamps

Glaciers. A mass of ice, fed by a permanent snowfield, slowly moving across a land surface is called a glacier. The engineer need recognize but two types: (1) Continental glaciers; and (2) alpine or valley glaciers. A continental glacier is an ice sheet broad enough to cover a large part of a continent to such a depth as to override all but the highest mountains. An alpine or valley glacier descends from a snowfield on the side of a peak, and moves as a long, narrow tongue down a valley.

Erosion. Glacial ice freezes fast to all loose material encountered, soil, sand and jointed rock that may be dragged out of place; these materials, carried along by the ice, may scratch and cut the rock surfaces over which they are dragged. Both bed-rock surface and carried pebbles are worn, striated and polished. A fine dust, called rock-flour, made of very minute particles of fresh unaltered minerals is the ultimate product of this grinding.

Tills and Moraines. All materials carried by the glacier will be deposited. The ice melts as it moves toward warmer regions, and drops the material carried in an unassorted heap, composed of boulders, pebbles, sand, clay and rock-flour, called till. Heaps or ridges or sheets of till are called moraines. The rolling, very irregular hills of the terminal moraine (Fig. 21) render cutting and filling always necessary, and generally very considerable. The boulders, sometimes 10 ft or more thick, commonly 1 to 3 ft, are both strewn on the surface and distributed irregularly thru the till (see Fig. 22). The gravel, sand and clay occur as mixtures of extremely variable texture and quality. The great boulders must often be broken up by hand, or by blasting. They may be used for road metal or aggregate when of favorable quality. The smaller boulders, up to 8 in, can be used as gutter linings, etc. Sand, obtained by sifting the till, always contains clay and rock-flour, but is perfectly usable for pavement block cushions, earth road surfaces, etc.

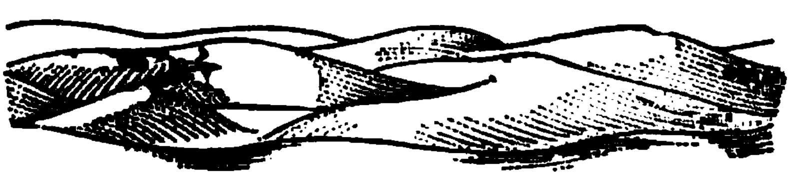


Fig. 21. Terminal Moraine

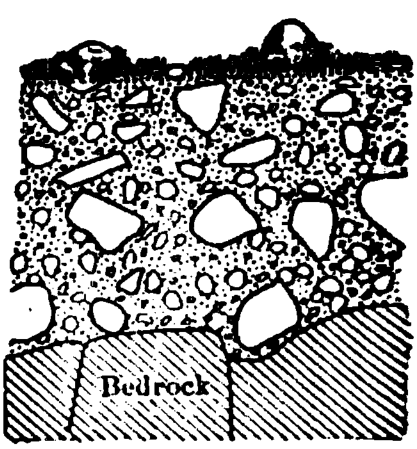


Fig. 22. Till

Outwash Plains. Water washes out sand and clay from the terminal moraine, and spreads it forward in a sort of alluvial fan, gently sloping away in front of the moraine. This is the outwash apron, or outwash plain (see Fig. 23). The flat southern plain of Long Island is the outwash of the terminal moraine that forms the east-west range of hills.

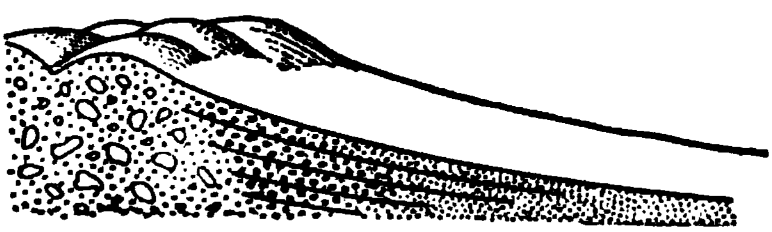


Fig. 23. Outwash Plain

Drumlins. The ice sheet may contain excess of plastic clay, especially when passing over a shale region. Just as an overloaded river forms shoals, so does the glacier deposit material, and by overriding it, smooth it into the shape of long, elliptical hills, called drumlins (see Fig. 24). There is usually a bedrock core, upon which the clay was plastered. Occasionally the drumlin is almost entirely rock. The clay contains boulders and sand, and has never been used for brick, tho often for fill and road material. Valleys between drumlins are badly drained and swampy.

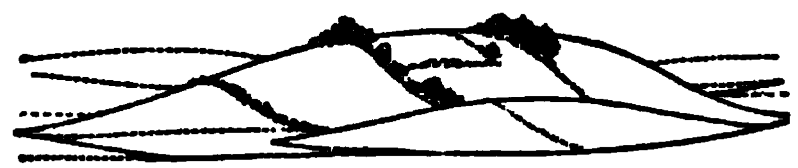


Fig. 24. Drumlins

Kames. Water from melting ice may be so heavily charged with débris that it rapidly builds a low mound or heap of sand and gravel, roughly stratified and cross-bedded. This is a kame, and may lie either within or behind the terminal moraine. Kames may be built as deltas into lakes formed along the margin of the retreating ice. In this case, they may be flat-topped, and of considerable extent, and are called kame deltas or delta kames.

Kames may be Recognized (1) by their form, as they are smaller and less irregular as a rule than moraines, sometimes flat-topped, and with digitated frontal shapes in the case of delta kames; (2) by their gravelly quality, seen on steeper slopes, where creep has torn apart the grass cover, or where streams have cut. They are composed of sand, gravel and small boulders, seldom over 8 in in diameter. The frequent shifting of the channel of the stream that made the deposit has caused a rapid alternation of the texture of the sediment. Gravel alternates with fine sand. The whole is complexly cross-bedded (see Fig. 25). Finer clay, as well as larger boulders is generally absent, but clay is present in some parts of the larger delta kames. Kames are a great source of gravel and sand which is obtained usually by sifting, or by working selected beds of suitable material. The sand is sharp and makes good aggregate. The rounded pebbles have been also used as aggregate in some important works, even where trap would have been available, as in many railway and highway improvements in eastern New Jersey. As kames are very pervious, they are generally unusable as material for dams. Perched water-tables sometimes occur, especially in delta kames. Usually the chief seepages are along the base of the kame.

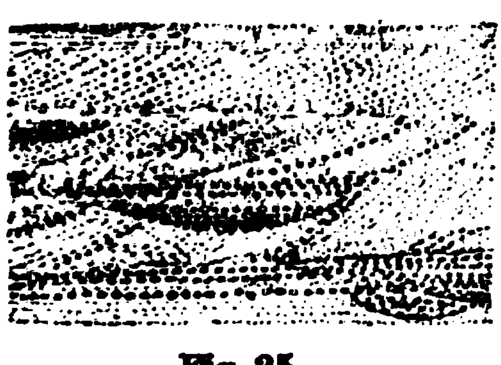


Fig. 25

Streams may develop under the melting ice. They transport and deposit sand and gravel, and when the ice melts, these stream-beds remain as long sinuous ridges called ESKERS. They are an important source of sand and gravel.

Lakes develop, especially during the retreat of the glacier. (1) Basins are formed between the moraine ridge and the retreating ice lobe. These may hold water for a time, but the lakes tend to disappear as retreat continues, and natural outlets are uncovered. (2) Tongues of ice may dam a stream valley, and form a lake, which disappears when the melting of the ice lobe frees the outlet. (3) Permanent dams of drift may back up the waters of a stream and form a lake, whose waters spill out wherever they may. The point of egress may change many times, if one wall of the lake be the ice sheet, or if the earth's crust be warping during the retreat of the ice. Such lakes will disappear when the outlet has developed a deep enough channel to drain the lake. The Great Lakes are of this type. Many great lakes have already disappeared. (4) Lakes occupy natural depressions in the drift. (a) Original hollows may be formed by the accidental placing of moraine ridges so as to enclose a hollow. (b) A block of ice may be buried in the moraine or kame as part of the deposit.

When it melts, the sediments slump down around the hollow it leaves, forming a steep-sided depression which will hold water if its lining is impervious. This is a KETTLE HOLE and the lake is a KETTLE LAKE. Lakes of types (1), (2), and (3) are evanescent, and more of them have disappeared than now remain. Streams discharging into them were richly laden with débris.

Lake Deposits were formed of débris washed into the lake by streams or waves. At the stream mouths, deltas were built, and bars and beaches were formed along the lake shores, while finer particles settled farther out, forming notable clay deposits. Today the dry lake bottoms appear as flat areas enclosed by hills, and trenched by the valleys of post-glacial streams. The larger streams have often carved flat terraces at several levels below the original lake bottom. Many gravel and sand pits are opened in the delta and shore deposits, while the clay masses toward the lake center furnish brick-clays. A surface layer of sand, thinning toward the lake center, often covers the clay. Roads do not usually follow the level top, but the later stream trenches so as to avoid bridging the latter. With the lake deposits may be grouped the CLAY TERRACES formed in narrow lake waters along the margins of tongues of stagnant ice in large river valleys, such as the Hudson. These are much used for brick making.

Summary. Glacial deposits were thus of three types: (1) Ice deposits, moraines, drumlins; (2) ice and water deposits, kames, eskers; (3) water deposits, outwash, lake deposits.

Combination of Types. Retreat of the glacier may form a lake, in which lake silts and clays may be laid, and into which kames from the ice, and deltas from the shore may be built. Then a temporary readvance of the glacier may cover the whole with sheet-till, or even build morainal ridges upon it. Kames and drumlins may also be covered with sheet-till. Several advances and retreats are frequently so recorded, all as minor phases of a general retreat. These facts give rise to conditions locally very puzzling, and often of great importance to the engineer. Buried valleys of preglacial streams are extremely common in regions of thick drift. They are far more interesting to the civil engineer than to the highway engineer, and no extensive treatment of them is necessary here. They are favorable to the concentration of underground waters, so that if a highway-cut trenches such a valley to below water level, very troublesome seepages may be encountered.

Water in Morainal Drift. The till is always more or less pervious, but usually contains enough clay to be relatively water tight in large masses, so that it forms effective walls for reservoirs and lakes. Pervious till may contain streaks of impervious clay, irregularly distributed, as shown in Fig. 26 by M. L. Fuller. Moraines may hold water: (1) As lakes and swamps in depressions; (2) as perched water-tables where descending ground water encounters a buried clay streak; and (3) as seepage along the contact between the drift and the rock floor upon which it rests. In making road cuts thru moraine country, all these sources of water may give trouble. Lakes must usually be skirted altho swamps and small lakes may be crossed on fill. They are usually not deep, but their depth is exceedingly variable. Perched water tables give elevated and troublesome seepages, sometimes causing clay slides. It is usually sufficient to cut well back from the road as the cutting lowers the ground water level, and may effectively drain the seepage. Streams heavily overloaded with sediment from the melting ice deposited the excess load upon their valley floors, thus building the floor higher. This filling up of glaciated valleys backed up the water of their

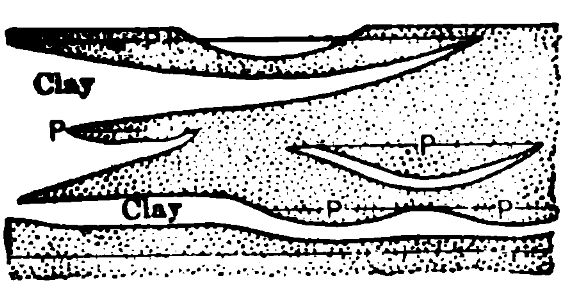
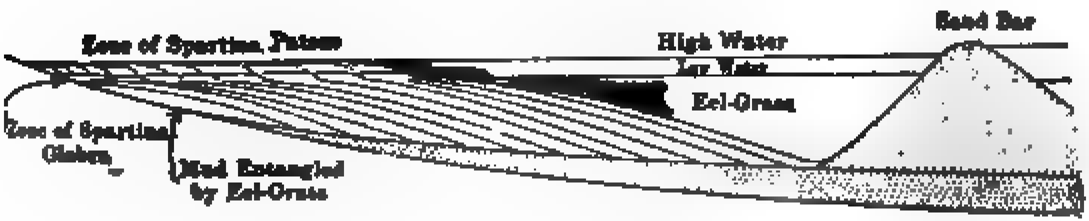


Fig. 26

tributaries, and forced these also to deposit, even when the tributaries drained regions that had not been glaciated. Later, all such streams cut down thru these deposits, leaving parts of them standing as flat-topped terraces (see Fig. 20) composed of clay, sand and gravel in variable proportions.

Swamp Deposits may be one of the following types: Peat, consisting of tightly compacted masses of sphagnum moss, which grows layer over layer, the newer plants overlying the old; reeds, ferns and swamp grasses in heavy tufts; and tree and shrub roots and stumps, in all stages of decay, which in some swamps predominate over all other materials; shells and their fragments, forming layers of marl out in the center where lake conditions prevailed for a time; diatomaceous earth formed under similar conditions; fine sediments, which have been washed in and entangled in the vegetable mat. These in various combinations occur giving many

(a) Fresh Water Swamp



(b) Salt Water Marsh
Fig. 27

types of fresh water swamp. The peat and other dense vegetation often form a floating mat overlying depths of stagnant water (see Fig. 27a). Fine sediments and decaying organic matter, saturated with water, and covered with a mat of growing plants, may form treacherous quicksands. Highway embankments sometimes sink out of sight when built across seemingly strong swamp surfaces.

Tidal Salt Marshes (see Fig. 27b) differ in many ways from fresh water swamps, but may offer somewhat similar difficulties to the highway engineer. The depth of swamps can be tested by simply pushing down a sharp iron rod. Their character is tested by driving down a pipe, and obtaining a core, but the samples are very much compressed.

PHYSICAL GEOLOGY

10. Folds, Joints, Faults

The structures described in this article are to be expected in all rocks having a definite laminated or bedded structure, including gneisses, schists, slates, and all the sedimentary rocks; as well as igneous bodies of sheet-like form, dikes, sills and surface flows. For simplicity, the sedimentary nomen-

clature will be employed in this discussion. Let the block diagram (see Fig. 28) be so oriented that the horizontal edges of the block lie east and west, north and south. The strata composing the western part A of the

Fig. 28

block lie horizontally. They illustrate the structures of plains and plateaus. The eastern two-thirds of the block represent folded strata, with much of the folds eroded away.

Dip. The inclination of a tilted stratum is called the dip. It is the angle included between the tilted bed and the horizontal, and is described in terms of the angle of tilt and the direction toward which the bed slopes down. Thus the dip of stratum *k* (see Fig. 28), is 30° East. The dip is measured by means of a clinometer, which consists of a protractor from whose center hangs a pendulum. The protractor is set with its straight diameter parallel to the dip (see Fig. 29) and the angle of dip is read by means of the pendulum.

Fig. 29

Strike is the direction traced by the dipping stratum when intersected by a horizontal plane. It would be the line of outcrop of the bed, if the earth's surface were horizontal. Strike is read with the compass, in terms of angular departure from north. Thus, in Fig. 28, the strike of the outcrop of *k* is North 21° East. The figure shows that beds with very different dip may have the same strike.

Axis, Limb, Anticline, Syncline, Monocline. The central line of a fold is called the axis (see Fig. 32, *aa*). The sides or flanks of the fold are called the limbs. An anticline is a fold formed by upward arching of the strata (see Fig. 28 B). A syncline is a trough-like fold, whose beds are bent downward (see Fig. 28, C). Monocline is a convenient term to denote strata dipping in one direction.

Fig. 30. Pitching Folds. A is Angle of Pitch

Variations. Folds are almost never symmetrical. The dip is usually steeper on one side of the axis than on the other (see Fig. 28). One limb is often longer than the other. The axis is rarely straight, for the fold as a whole follows a sinuous course. The axis is seldom horizontal, but inclines, and the angle of its inclination from the horizontal is called the PITCH (see Fig. 30A). All folds at the surface of the earth are eroded. Mountains and valleys depend not on their structure, but upon hardness of rock. Thus, in Fig. 28, *k* and *p* are monoclinal mountains, *c* is an anticlinal mountain, *e* is a synclinal

mountain, *b*, *d* and *f* are monoclinal valleys, *h* is an anticlinal, and *m* a synclinal, valley. There is no synonomy between anticline and mountain, syncline and valley. A hard rock of gentle dip develops during erosion a gentle slope on the dip side, where the softer beds were washed away from its surface, and a steep slope where its uptilted edge juts out. Such a mountain is called a CUESTA (see Fig. 28, *k*).

There are Three Common Methods of Solving Folds. 1. THE DIP METHOD. Take the dips of a given, recognizable stratum at several successive outcrops, as in Fig. 28: (a) If the dips incline away from each other, as in B, the fold is an anticline; (b) if the dips incline toward each other, as in C, the fold is a syncline.

2. THE SUCCESSION METHOD. Determine the relative age of two or more recognizable beds or formations. Then, in Fig. 31, let (1) be the oldest (lowest rock formation); (2) the middle; and (3) the youngest (highest). Figs. 28 and 31 show that (1) in crossing eroded anticlines, the oldest bed occupies the axis of the fold, and the succession in going from margin to axis to margin is, from younger to older to younger; (2) in crossing an eroded syncline, the youngest bed occupies the axis, and the succession is from older to younger to older.

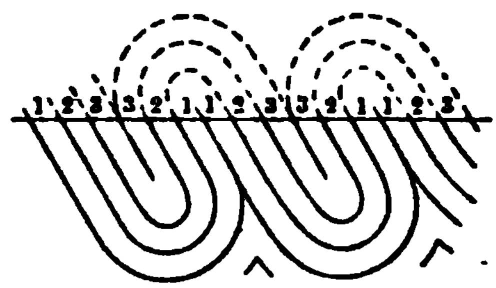


Fig. 31

3. THE TOPOGRAPHIC EXPRESSION OF THE ERODED FOLD. This is especially useful when the fold pitches. A pitching anticline erodes to a parabola-shaped outcrop pointing with the pitch, A, Fig. 30. A pitching syncline erodes to a parabolic outcrop, the apex pointing opposite the pitch, B. If the rocks are of alternate hard and soft beds, a very common case, then (1) the anticline weathers into a parabola-shaped outcrop having the steep slope on the inside of the curve, the gentler slope on the outside; and (2) the syncline has the steep slope on the outside and the gentle slope on the inside of the curve. See Fig. 32. This method is especially useful, not only in the field, but in determining structure by means of topographic maps.

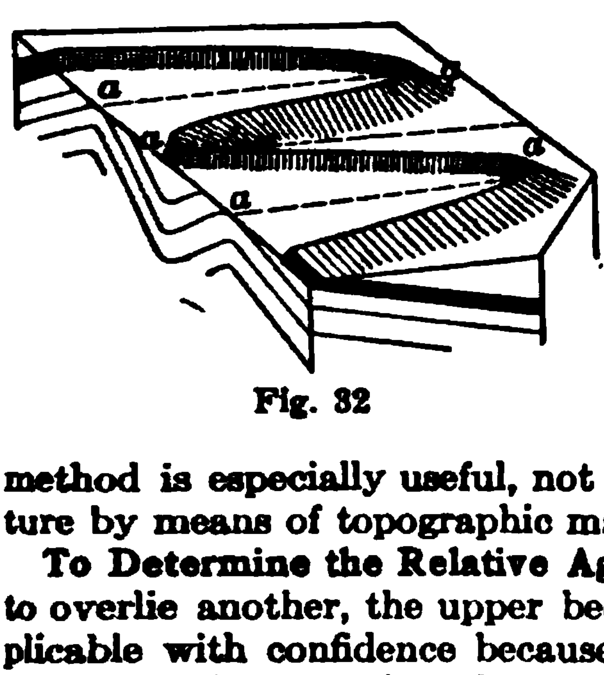


Fig. 32

To Determine the Relative Ages of Beds: (1) If one bed is clearly seen to overlie another, the upper bed is the younger. This method is not applicable with confidence because of the overturning of folds in regions of complex folding and faulting. (2) Fossils, which are remains or impressions of organisms in the sedimentary rocks are often definitely characteristic of a given age, and the relative ages of strata can be determined by identifying their fossil content. (3) If the pitch of a fold be recognized, the younger beds are always encountered successively in walking toward the direction of pitch. The older beds are always met with in going away from the pitch. This rule holds whether the fold be anticlinal or synclinal, and is especially useful in complex countries.

Joints are the cracks or fractures that traverse rocks. They are present in all rocks of the earth's crust. They generally exist in somewhat orderly systems, so that groups of joints rudely parallel to each other may be recognised in three systems: Two sets of intersecting joints approximately

vertical, and a group approximately horizontal. They are most numerous near the surface, and tend to die out downward, so that larger blocks are encountered in depth. They are a controlling factor in all quarrying operations, for the shape and size of available blocks are determined primarily by the joints.

Occasionally joints are placed with great regularity, especially in igneous rocks, or thick bedded sedimentary rocks, thus permitting the extraction of well shaped dimension blocks. Irregularity of system is the rule, however, and few exposures of rock are fit for building stone quarries, even when of the proper rock quality. Regular and favorably spaced joints are a condition wholly essential to good building stone quarries, but irregular and numerous joints are favorable to extraction of rock for crushing. Joints facilitate movement of ground waters, and h nce, the weathering of rocks. They reduce the cohesion of rock masses, and favor landslides.

Sheeting in Gran'tes. A system of nearly horizontal joints tending to be parallel to the hill surface traverses most workable granite masses. In the quarry these joints appear to divide the rock into flat sheets; but the fractures curve slightly and intersect each other, so that the sheets are lens-shaped. The importance of the lenticular form lies in the fact that as the lenses overlap, the thin edge of one lies upon the thicker part of another, giving the quarry rock a variable thickness. Thus, large and small blocks may be extracted at will. As a rule the sheets are thinnest near the top of the quarry.

A Fault is the displacement of rocks along a fracture. Several types of faults are illustrated in Figs. 33 and 34. It is not necessary for the highway engineer to solve a fault, as to amount and direction of displacement, but it is necessary for him to know some of their effects, and be able to recognize their presence. Only matters of importance to the highway engineer will be treated. The rocks in a fault zone may be polished and striated by the gliding of the rock surfaces during displacement. This is called SLICKENSIDING. Not only is the plane of principal displacement slickensided; many adjacent planes of minor movement, parallel to the main fault plane, are usually polished also.

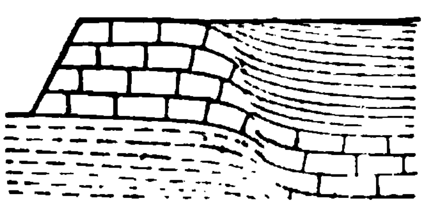


Fig. 33. Normal Fault

Faulting often crushes and shears the rocks in the plane of greatest movement. The CRUSH ZONE may vary from a few inches to 100 ft or more in width. It may also be accompanied by many minor parallel displacements, often slickensided. The fault plane may be filled with a very fine, unctuous clay-like material called GOUGE. It may be washed-in clay, or finely ground-up rock, due to extreme crushing, or weathering products in the fault plane, or any mixture of these. The fault zone favors the movement of ground waters, and thus extensive weathering of rock in the upper part of a fault zone and precipitation of material deeper down are to be expected. When the fragments in the crush zone have been cemented together, they form a rock called FAULT BRECCIA.

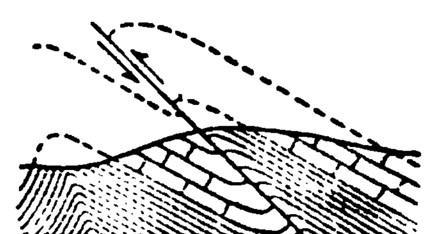


Fig. 34. Thrust Fault

From the above, it is seen that: (1) Faults are very favorable to landslides; (2) extensive seepages are to be looked for along fault zones, especially in tunneling; (3) rock along fault zones is apt to be weathered and stained, and unfit for use; (4) dimension blocks cannot be obtained, as a rule, near faults; (5) rocks weakened by faulting give great trouble in tunneling, and may require very careful timbering.

Faults may be Recognized: (1) By observing the displacement of the rocks, that is, failure of beds, dikes, etc, to match on the two sides of a fissure; (2) by slickensides, crush zones, breccia, clay-gouge filling, etc; (3) by topographic features, such

as the fault scarp, or cliff due to displacement, or, if it has been wholly eroded away, as is commonly the case, (a) valleys may develop along the weak rock caused by faulting, and these valleys often cut across the strike of the rock, (b) cliffs due to outcrop of hard rock may be abruptly offset by faults, as shown in Fig. 35. See also Arts. 15 and 16. Valleys develop along these offsets, as in (a), giving an easy grade up the cliff. Roads and railroads are frequently located on these fault lines.

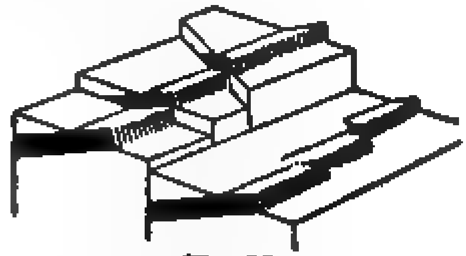


Fig. 35

11. Streams

Young Rivers, upon a newly uplifted or a mountainous surface, develop the following characteristics: (1) A deep narrow valley, V-shaped in cross section, the river occupying the whole of the valley floor; (2) as steep a gradient as the topography permits, and as rapid a flow as the gradient causes; (3) falls and rapids, where the river passes from a hard rock-bed to one of softer rock; (4) lakes and swamps; (5) usually a very irregular course.

Examples of such streams are: The Niagara River system with the Great Lakes, falls, rapids, and gorge along its course; the Columbia, Snake and Colorado Rivers and their branches; nearly all mountain streams. Young streams afford practically all the water power in the world. Their narrow deep valleys, their lakes, and their usually limited water-sheds make them easy to dam and control for water supply. The solid rock floors of most young streams are favorable to the location of bridge piers. The rapid current, especially if the river is wide or deep, may give trouble, sometimes needing to be crossed by a single bridge span. Roads along the sides are especially liable to creep, landslide and seepage nuisances, and necessitate the most careful study. See Art. 12 and 13.

Mature Rivers. Given time enough, the young river will (1) cut down its valley bed until it has just sufficient slope to flow, and (2) will widen its valley floor by undercutting its banks, until the mature river presents the following characteristics: (a) A broad open valley, with gently sloping sides; (b) a comparatively gentle and regular gradient, (c) a meandering course, in which the size or radius of the meander curve bears a general constant relation to the volume of the stream; (d) a flood plain, floored with alluvium, and often swampy; (e) natural levees, as described below; (f) shoals and bars; (g) cut-offs and oxbow lakes; (h) a well developed system of tributaries.

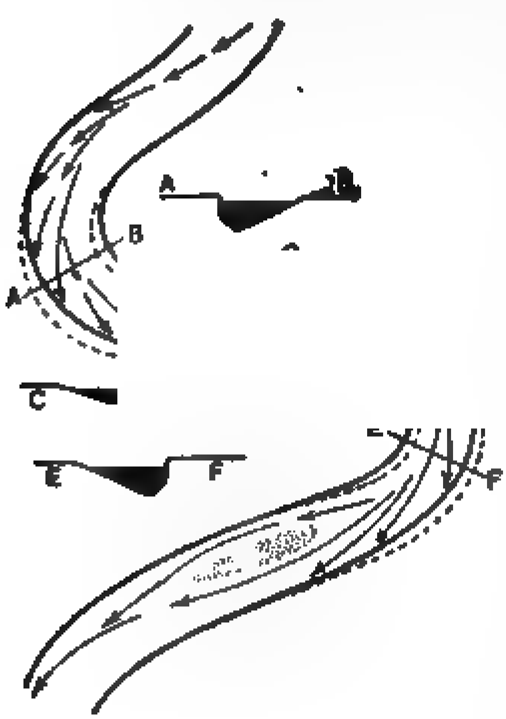


Fig. 36. A B and E F, Meanders and Bends: C D, Crossing

Meanders and Crossings. The river undermines the concave or outside bank of a meander (see Fig. 36, A and F), causing falls of material, which the stream gradually erodes and carries away Thus the meander is enlarged gradually (see Fig. 36, dotted line). The undercutting continues downstream from the meander curve along the same bank. Roads located on the undercut bank are subject to destruction,

especially in time of high water. They should either avoid running too close to the bank, or, as this is very often impossible, should be protected from undercutting. The bank may be faced with cobbles. Riprap too heavy for the river to displace may be dumped along the foot of the bank. The bank may be faced with brushwood or piling, or sodded with tough stout grass. Bank protection is a complex subject, and the engineer is referred to the excellent work of Thomas and Watt (14) for details. The channel is deepest and the current strongest, near the undercut bank, (see Fig. 36, arrows). The opposite or convex bank of a bend is the scene of deposition by the river. As the meander enlarges, the entire river channel shifts, moving both outward and downstream, as shown in Fig. 36, dotted lines. The convex bank is thus built or added to, while the concave bank is being eroded. As two adjacent meander curves enlarge, they approach each other, until only a narrow neck of land separates them. This isthmus may be broken thru, and the river then runs directly across the neck; the abandoned channel remains as a meander-shaped OXBOW LAKE (see Fig. 37, A). This is only one of the methods by which mature rivers shift their channels, and the change often produces serious economic effects. In passing from one bend or meander into the next bend, the river that was undercutting, say, its left bank must now erode its right bank. Thus, the entire current must cross the river from the left undercut bank where it was concentrated, to the right bank, (see Fig. 36, arrows). The straight part of the river's course between two bends is therefore called the CROSSING. It is shallower than the bends, and tends to develop shoals. Bridges are often built at crossings.

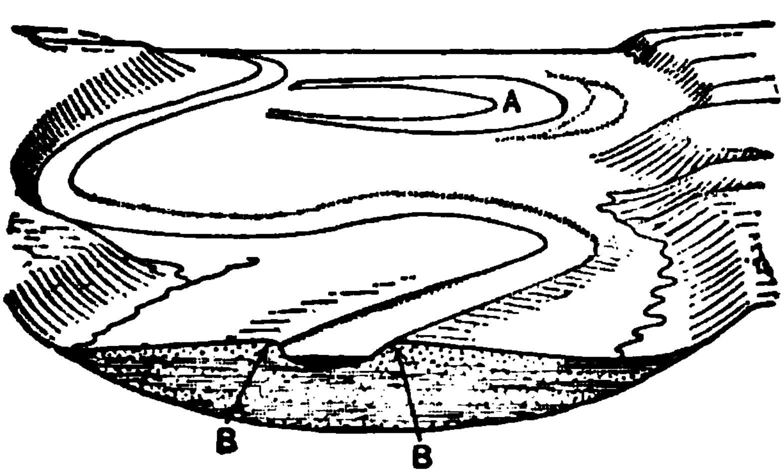


Fig. 37

Deposits. The transporting power of running water varies as the sixth power of its velocity. Thus, if its speed be doubled, its carrying power will be increased 64 times, and a slight diminution of rapidity will cause the immediate deposition of sediment. The beds of young hillside streams are commonly floored with gravel and boulders which they can only roll along in time of freshet. Such gravels are often available for road making in the main valley below. When mature rivers in broad valleys overflow their banks, they drop their coarsest débris close to the bank, where the speed was first checked. Silt is carried farther, and laid down along the flanks of the valley floor in quiet water, away from the main channel. This happens repeatedly, so that the coarse deposit near the stream is built up into a ridge or retaining wall, higher than the rest of the valley. This ridge is called a NATURAL LEVEE (see Fig. 37, B B). In parts of the southern Mississippi valley, roads, railroads and houses are built on the natural levee, for the rest of the flood plain is swampy. In general, flood plain deposits are alternating beds of gravel, sand, silt, clay and plant remains, stratified and often cross-bedded. They form level lands, well adapted to highways, and their variable character makes it often possible to open gravel and sand-pits, develop local clay beds, etc, for road materials. The lower courses of long river valleys lack the coarser grained débris.

The delta lands of the Mississippi and the Colorado Rivers, for example, contain only the finest silts. Rock for road making must be brought from a distance to such places. Bed-rock often lies very deep in a mature river valley, and the alluvium forms the only available base for bridge piers. This is, however, often dense and well compacted, but quicksands, slippery clay beds and copious movements of ground water are all to be expected. For bridges of any size, deep wash borings should be taken to test the ground. Piling is not infrequently used in soft or swampy ground. In planning roads, it is always well to cross stream valleys at right angles when possible.

Alluvial Cones. A young stream emerging abruptly upon a plain or larger valley finds its speed checked, and so drops sediment. It thus builds up a cone-shaped dump heap, sloping outward from the mouth of the young stream's canyon. The coarsest débris forms the apex of the cone, and the finer silts are washed out to the margins. The stream often sinks thru the coarse gravels, and vanishes, only to re-issue at many springs where it percolates down to the finer, more impervious silts at the margins. This deposit is called an alluvial cone.

Deltas. Rivers entering lakes, seas, or larger streams, may deposit their load so as to form a flat-topped, cross-bedded deposit called a delta. The stream breaks up into minor, diverging channels on the delta, and each builds a finger-like extension of the delta. But waves and shore currents may greatly modify the typical delta form. The materials will be coarsest near shore, and in the stream channels; finest farther out, and along the bottom. See also Art. 9, GLACIAL DEPOSITS.

12. Underground Waters

Ground Water is the water which sinks into the earth and moves thru cracks and pores in soil or rock.

Underground Reservoirs are cavities holding water. They include: (1) Pores, due to original space between grains, gas bubbles in volcanic surface flows, pores made by solution or by washing out of fine particles from among coarser grains; (2) cracks, due to joints, faults, rock cleavage, mineral cleavage, bedding and schistosity planes; and (3) caverns resulting from removal of rock matter in solution. Any water-bearing stratum or fissure is termed an AQUIFER.

Movements. Ground water moves thru the pores in the rocks, and along all fissures or cracks. It moves more rapidly thru larger cracks, larger pores, straighter pores; and more slowly thru thinner, smaller or more tortuous openings; faster thru sheet-like cracks than thru tube-like pores. It moves relatively faster on steep slopes and when nearer the surface than thru level lying material or when deeper in the earth. The water moves first directly downward, until a depth is reached at which the earth is saturated. This is called the GROUND WATER LEVEL, G. W. L. In region A (see Fig. 38), it moves more rapidly, and the G. W. L. is lower. In B it moves more slowly, and so piles up. Thus the G. W. L. roughly follows the contour of the hill. The arrows give not only the direction of movement, but their length is proportional to the speed of the flow. Along impervious surfaces there is a lateral movement, even if the surface is horizontal. In Fig. 38,

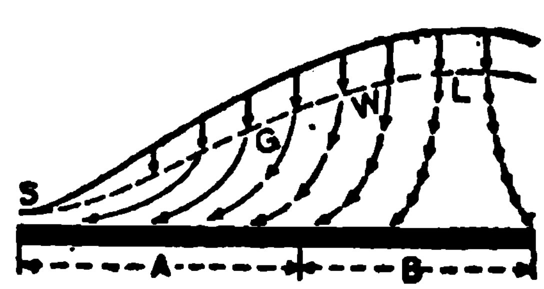


Fig. 38

spring or seepage will develop at S. The direction of flow, primarily controlled by gravity, is influenced also by (1) the dip of porous beds, (2) the presence and arrangement of impervious layers, (3) the position of joints, tubes and other fairly open passageways, (4) the arrangements of grains in a bed. Most sand grains have a longer and a shorter axis. When deposited, they tend to lie with their longer face horizontal (see Fig. 39). Thus they offer fairly continuous horizontal passages for the water, but render vertical movement difficult. Since ground water moves faster in open fissures than in small tortuous pores, any open crack will drain the water out of the porous matter surrounding it. The G. W. L. is lowered locally by such drain. Thus a swamp can be drained by cutting ditches in it. Road cuts on hillsides lower the G. W. L. in their neighborhood. Fig. 40 shows original G. W. L. at *a*. The cut and fill lowered the G. W. L. to *b*, and the drain lowered it to *c*. Joint and fault planes facilitate ground water movements, and become great avenues thru which the water moves. In regions of crystalline rocks, as in Maine, these cracks are a considerable source of water supply (see Fig. 41 by M. L. Fuller).

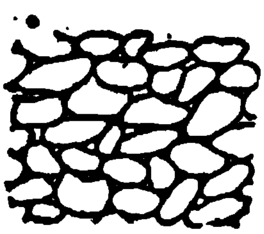


Fig. 39

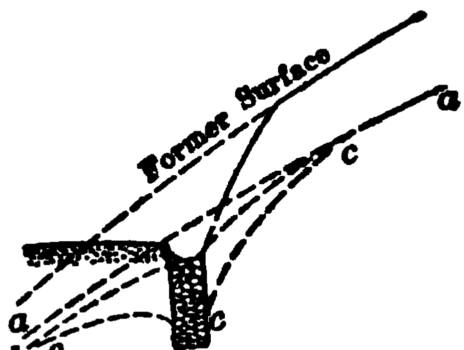


Fig. 40

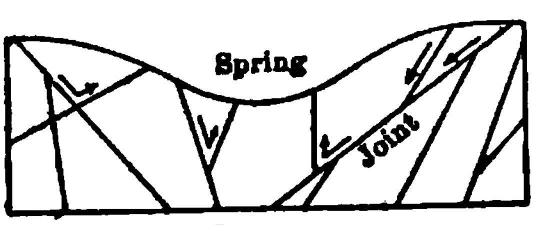


Fig. 41

Porosity of Sand and Gravel. Beds of gravel and sand have 30 to 50% pore space, and readily permit the passage of water. Gravel transmits water about 35 times as fast as does fine sand. The finer the grain of the sediment, the slower is the movement thru it. A fairly coarse, pure sand will permit ground water movements more than 100 times as rapid as are possible thru sand mixed with clay. In the field, the amount of water that can drain away thru a given soil will depend not so much on the percent of voids, as on the relative sizes of grain, and the quantity of each size present. But the slope of soil, the proximity of ponds or streams, feeding the soil by seepage, the presence of some easy avenue of escape, like a cut, are among the many modifying influences. Schlichter has measured flows as rapid as 96 ft per day in the sandy soil of southern Long Island, the average near the surface being 5 to 15 ft per day. But no given figures can be taken as a guide except for the place where they were obtained. Gravels and clean sands can be regarded as very porous substances, clays as impervious, and other mixtures judged by their observed behaviors.

Porosity of Rocks. Sandstones and conglomerates are often porous, even to the extent of 15% of their bulk. Shales and clays are even more porous, but their pores are so very small and tortuous that water movements in them are very slow. Hence, clays are ranked as impervious material. But shales and slates are strongly cleaved and jointed, and may contain much water moving thru these larger openings, except when these become choked with clay. Limestones are usually dense, but may be porous, especially in certain granular and shell-rock varieties. Water in limestones moves along joints and bedding planes. These crevices become enlarged by solution (see Fig. 44). Channels like little valleys branch across bedding surfaces. In time the cavities may enlarge until great caverns, like Mammoth Cave are formed. The cavities may collapse under load, causing settling of bridge piers, etc. In limestone countries the rock should be explored for evidence of cavities before building any heavy structure. Drilling should be resorted to in the case of very large foundations, but for small structures a study of the outcrops will probably reveal any serious weakness. Crystalline rocks, igneous and metamorphic, contain water only in their fracture planes. Their pore space is usually very small. Marbles are rarely porous, but are subject to solution as are limestones.

Seepages. A seepage is the quiet emergence of water along some rather extensive line or surface, as contrasted with a spring whose water emerges from a single spot. The term also refers to movement of water beneath the surface, as the seepage from soil into a lake or stream. Ground waters move downhill, and concentrate in valleys, so that the G. W. L. is often nearer the surface in the valley. But the reverse may be true if the valley is deeply filled with very porous alluvial deposits. A swamp develops when the G. W. L. is just at the surface. The surface stream in the valley may have cut its trench down to or below the G. W. L. In this case, the general movement law provides that the ground water will seep into the river, increasing its flow. If the river has not cut to G. W. L., the river water tends to sink into the ground to join the ground water. The river is then very apt to be intermittent, flowing only in times of great supply. Similarly, lakes and ponds may either feed the ground water body, or be fed by it, according to the relative levels of lake and G. W. L. (see Fig. 42). Ground water moves thru porous material, and along impervious matter. Hence, seepage may occur wherever an impervious bed crops out on the downslope side. Underneath a cover of transported soil, especially glacial drift, the ground water will often concentrate along the impervious bed-rock surface. Seepage will occur where this surface slopes downhill, and is laid bare by natural or artificial cuts. The amount of seepage depends upon rainfall, depth of soil, slope, area involved, etc. Seepages develop where porous sand is underlain by impervious clays. Often the presence of the clay is revealed by the numerous seepage springs arising from the contact. In clay pits these often give trouble. See Art. 8.

Fig. 42

Springs are classified as ARTESIAN SPRINGS, which rise to the surface under head, forced upward by the pressure of confined ground waters, descending from higher levels; and GRAVITY SPRINGS, those which simply issue where the exposure of a water-bearing stratum gives upon the surface (see Fig. 38). They have also been classified as SEEPAGE SPRINGS, TUBULAR SPRINGS and FISSURE SPRINGS. Seepage springs are merely those seepages which issue from a small definite area. The water will follow any irregularities that chance to form natural channels in the surface along which the water moves, such as clay or hard rock, and so may emerge at a definite point. Tubular springs (see Fig. 43) are formed in two ways: In loose sediments, clay or glacial drift, water may wash out fine particles of clay, forming a tubular passage, which may either be hollow, or contain loose sand and gravel. These passages may be very long and have many branches. Tubular solution passages may be formed in limestones in the manner described above (see Fig. 44). Fissure springs occur wherever a joint, fault or other natural rift gives upon the surface at a point below the water-level in that fissure (see Fig. 41).

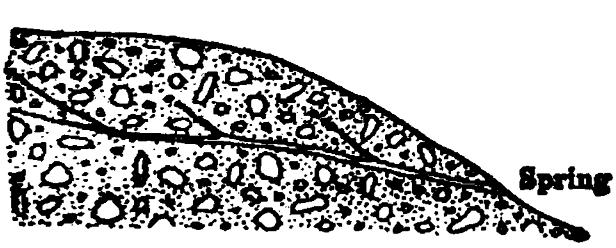


Fig. 43

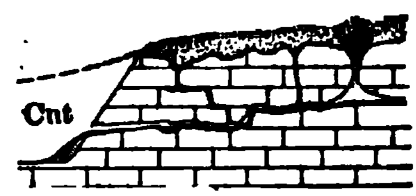


Fig. 44

Where a Highway Cut breaks into water-bearing strata, seepage develops as follows: (1) The cut may intersect the G. W. L. of the soil (see Fig. 40). The G. W. L. is at once lowered in the neighborhood of the cut, and water will seep out on the surface. Ditches and underground side drains will take care of the water; (2) a deep cut in sandstones, especially if

the dip is toward the road, and if the sandstone is confined between beds of impervious shale, may develop damaging seepages. The narrow, sheet-like solution-cavities in limestones are far more numerous than the great caverns; the water movements in both are quite the most rapid known for underground waters. A road cut may trench one of these underground waterways, and liberate a stream of water for which a special drainway may have to be built. See Fig. 44. Water in glacial drift is treated in Art. 9.

Ground Waters Near the Surface may Freeze, making a crust of ice some feet beneath the surface. But where the G. W. L. lies deeper, say, higher up the hill (see Fig. 45), the freezing may not take place. If now, the G. W. L. be raised, the water under the ice crust will be pressed upon by the greater height of the water column in the unfrozen part. This will cause an upward hydrostatic pressure under the ice crust in the valley below, perhaps under the roadbed. If the crust melts, or fractures, water will rise under pressure to the surface. There is no cure for this condition save to provide carefully for the underdrainage of the roadway by any standard method. The filled broken stone trenches, V-drains, etc, are adequate to carry off the water and relieve the pressure.

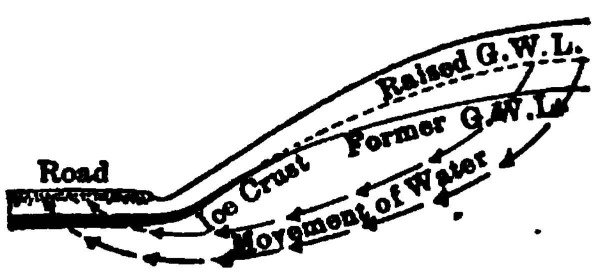


Fig. 45

Clay, Soil over Rock. Fig. 46 shows residual colluvial soil or clay surface covering creeping down a hill. Ground waters move readily thru broken rock of subsoil, confined between clay soil above, and solid bed-rock beneath. Under ordinary conditions, water will not rise in the roadway, but when storms, melting snow, etc, have raised the G. W. L., water will develop head or pressure under the subgrade, rising thru the somewhat freer openings afforded by the broken stone roadway and by the fact that the shallow roadway cut has removed the clay cover. A deep draining-trench with tile or broken stone at the hill-side of the highway (see Fig. 46) solves the difficulty. A V-drain is not necessary. The same problem will arise in a glaciated country if a fairly impervious clay glacial soil overlies a sloping rock surface, along which seepage may take place either thru sand, or rock joints, or even upon the hard rock surface, where concentration of ground waters will wash out finer particles and make passages for itself.

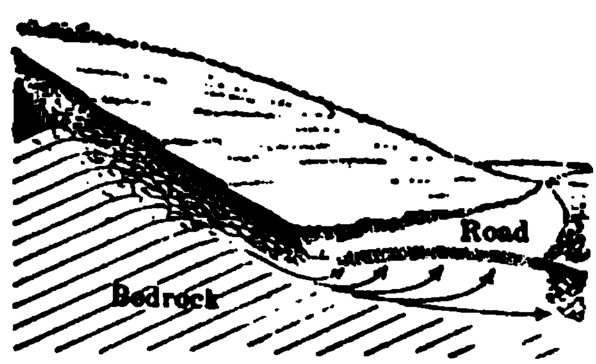


Fig. 46

Need of Roadway Drainage is also indicated by visible springs, dry gullies, which hold water in time of freshet, close proximity to water bodies whose level may rise and change the G. W. L. Under-drains are not required on all hillsides; the engineer must study the questions: (1) Has the cut penetrated below the G. W. L., and (2), is the G. W. L. likely to rise enough to injure the roadway unless underdrained?

13. Landslides and Related Phenomena

Few geologic conditions are a more constant problem to the highway engineer than the possibility of slides. Only those types most likely to affect highway work will be discussed.

Heim's Classification of Slides, translated by Ries (13), follows:

- Landslides
  - Movements involving detritus
    - I Soil slips
    - II Earth slides of greater magnitude than (1)
  - Movements involving solid rock
    - III Rock slips
    - IV Rock falls
  - V Compound slides with respect to character and movements of materials
  - VI Unclassified and special cases

General Conditions Affecting Landslides. Internal conditions: (1) Physical condition of the rocks; (a) crushing strength of large masses of the material involved, (b) tensile strength of large masses of the material involved, (c) strain conditions in the rock mass, (d) cohesion of the rock masses, (e) presence of soft layers, either as beds of sediment or the filling of joints and fault planes; (2) structural conditions, folding, faulting, jointing; (3) topographic conditions, oversteep hillsides, cliffs. MacDonald (22) states that both (1a) and (1b) vary according to the strength of the small component masses, the character of the jointing, the character of the bedding, and the fault conditions.

External conditions: (1) Amount and character of ground water, its distribution and movements; (2) readjustment of stresses within the mountains; (3) earth tremors set up by earthquakes, blasts, passage of railroad trains, etc; (4) freezing of water in rock openings, and wedging-off of rock masses; (5) undercutting by streams, or oversteepening by artificial excavations; (6) heavy structures, as bridge piers, adjacent to the excavation, and other minor causes.

Usually there are a series of slowly cumulative, remote causes, such as long weathering, undermining, overloading, etc, which continue until a critical point is reached, when some more immediate cause may start the sliding. Shock due to blasting is a less efficient cause than is usually believed, unless the blasting be right against the slide material. Undermining or oversteepening and overloading are causes, not only important in nature, but also are produced artificially in engineering work. Water-soaking is the most widespread of external, immediate causes, since most of the recorded slides have occurred after heavy rains.

Oversteepening and Overloading are of especial importance in highway work. An excavation removes the side support of the standing rock mass, and substitutes atmospheric pressure for the pressure or support of the mass removed. Thereupon stresses develop in two directions (see Fig. 47), *a* downward, and *b* horizontally toward the cliff. Both stresses are, of course, due to gravity. The arrow *c* may represent the resultant of the two. If the shearing force *c* is greater than the cohesion of the mass, a slide will occur.

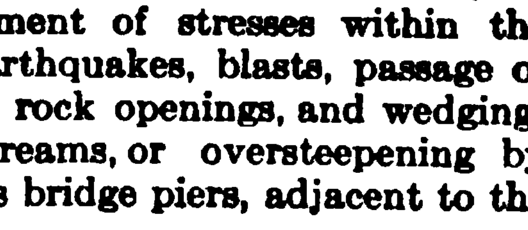


Fig. 47

MacDonald (22) calls the angle between the shearing force *c* and the vertical *a*, the angle of shear or angle of pull. A more nearly correct expression of the stresses is shown in Fig. 48, in which FF bounds the mass which will slide, separating along the fracture FF; BBB, the original profile; CCC, the deformed profile, just before sliding; and the arrows, the deformative stresses, as modified from MacDonald (22).

Soft rocks may actually bend and deform under the pressures, so that the crest of the cliff may sink, the face bulge forward, and even the bottom of the excavation may swell or bulge upward before the slipping begins. MacDonald calls the zone within which this deformation may happen the EXCAVATION DEFORMATION. It varies with the height of the cut, character of rock, planes of weakness, slope of original surface, ground water, etc. The ANGLE OF REST is the angle at which loose matter can stand without sliding. It is often 30° to 35°. The ANGLE OF SLIDE is the angle at which a given mass will start sliding. It is measured, like dip, in degrees departure from the horizontal and depends upon all the complex conditions discussed in this Article.

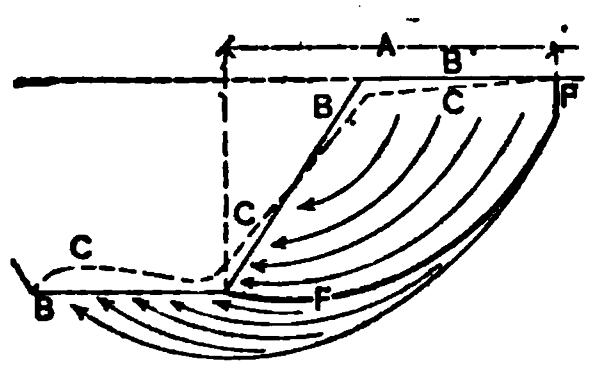


Fig. 48

Type I. Creep is a slow natural downward movement of loose material on hillsides, and is classified under Type I. Altho slow, its universal presence and serious consequences make it the most important slide movement which highway engineers must consider. Causes. (1) When water-soaked, the loose matter is heavier, better lubricated and more plastic, and tends to slip slowly down hill. (2) Freezing water expands in the soil, and lifts up and wedges apart the pebbles and particles. The frost melts and seeps away, leaving the soil mass in a spongy condition. It soon packs down again, but every particle will settle a little downhill from where it lay before the frost. (3) Percolating ground water dissolves material out of the soil and loose rock, increasing the porosity, and tha subsequent settling or packing of the porous mass always moves the matter a little down slope. (4) Springs and seepages wash out particles (see Art. 12 and Fig. 43). They also smooth the gliding surfaces, and in many ways promote creep. Creep may bend over the upturned rock strata to a depth of 10 ft or more, so as to reverse the dip, and simulate folding (see Art. 12, Fig. 46). Very large masses may be moved, exerting great pressure. Highways laid along the talus slopes of cliffs, or on the creep material of hillsides are moved with the creeping-matter. Tracks and pipe lines are displaced. At Virginia City, Nev., on the slopes of Mt. Davidson, the first water mains had to be built with long telescoping joints to allow for stretching in creep. Near Field, B. C., the Canadian Pacific Railroad track is from time to time displaced by creeping of the talus slope on which it is built. Retaining walls, stripping away of loose material, or widening of the excavation may be necessary.

Type II. Earth and Clay Slides are sudden and rapid movements. The primary conditions are usually: (1) A considerable superincumbent weight; (2) a slope, which need not be steep; and (3) the saturation of some clayey layers with water, so as to lubricate the sliding surface. Clay slides occur not only on mountain sides, but in valleys where clay terraces stand above river levels, as along the Connecticut and Hudson Rivers. A steep slope is not a necessary condition.

Type III. Rock Slides are the type most frequently mentioned in text-books on engineering. Rock slides are conditioned by bedding, cleavage or joint planes dipping toward the excavation, and may occur on a small or large scale, along highway or quarry cuts. It may be necessary to cut the excavation slope to coincide with the bedding planes, as shown in Fig. 49. Failure of bridge piers may be caused by rock slips, if the rocks under the pier foundation dip streamward, and contain interbedded shale or clay members. The pier overloads the rock, which slides upon the lubricated surface of the wet clay.

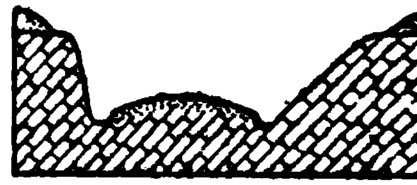


Fig. 49

Type IV. Rock Falls may occur on any steep rock face, if the conditions stated in the beginning of this Article are favorable. The falls recorded have almost all been connected with excavation of some sort, such as mining, railroad cutting, undercutting by streams or sea-waves. The excavation causes

oversteepening and removal of support. Heavy rains, frost, and earthquakes are among the other recorded external causes, while joints, faults, clay gouge, weak beds and steep surfaces are recognized internal causes. At Frank, Alberta, in 1903, a mass of rock about ½ mile square and over 400 ft thick fell, and the danger of further falls have made advisable the removal of the town of Frank. The La Pita slide in Culebra Cut, where 20 000 cu yd of rock were displaced along fault planes lubricated by seepage is another example. A highway built along the foot of a cliff is always in danger from rock falls.

Type V. Rock Falls may Descend upon Loose Material and start the latter sliding Compound slides present no more complex problem for the engineer than do the types already considered.

Table VI.—Slopes to Adopt at Different Depths for Deformable Rocks

Depth of Excavation		A	B	C	D	E	F	G
Feet	Meters							
33	10	50	40	30	20.0	12.0	7.0	5.0
66	20	41	33	25	17.0	10.3	6.1	4.2
98	30	36	28	21	15.4	9.3	5.6	3.6
131	40	32	25	19	14.4	8.6	5.2	3.2
164	50	29	22	16	13.5	8.0	4.9	2.8
197	60	26	19	14	12.7	7.5	4.6	2.5
230	70	24	18	13	12.0	7.2	4.4	2.2
262	80	23	16	12	11.4	6.8	4.2	2.0
295	90	21	15	11	10.8	6.5	4.0	1.9
328	100	20	14	10	10.2	5.2	3.9	1.8

Explanation of Table VI. MacDonald (22) has devised a table of slopes that are safe for various grades of weak rocks, with allowance for jointing and shearing. The figures given in lettered columns are to be read with the words 'on 10" understood. Thus, "50" reads "slope of 50 on 10." (A) Soft and weak sandstones, shales, few limestones, and tuffs, which will deform slowly under great pressure. Deformation of such rocks has caused swelling ground in coal mines. (B) The same rocks as A, but with medium shearing and jointing. (C) The same rocks as A, greatly sheared and jointed, or dipping toward excavation. (D) Soft volcanic clay rocks, bedded friable tuff, lignitic shales, with high water content. Fine to medium grained. The rocks have a minimum of fissuring and bedding. (E) The same rocks as D, but with the jointing, fissuring and bedding of average rocks. Most of the slides in Culebra Cut, Panama, have occurred in rocks of classes D and E. (F) Any extremely soft rocks that are much crushed and rendered slippery by ground water, talcose clays, etc. Rather stronger than ordinary creep material.

In some cases it will prove economical to cut the slope back in terraces of moderate height, each higher terrace farther back than the one below, instead of making one single slope.

14. General Structure of the United States

The New England Province (see Fig. 50, A) consists of ancient crystalline schists and gneisses, very complexly folded and faulted. These are cut by large and small igneous intrusions of many different ages, some preceding the period of metamorphism, others of later date. Hence New England is a great source of granite. The complex structure is in part reason for the irregular, rolling topography of rounded hills rising gradually toward the northwest to about 3000 ft. Patches of more recent rocks are infolded or infaulted in the crystallines, and develop special topographic and soil conditions. The Boston Basin, A1, is an infaulted patch of soft,

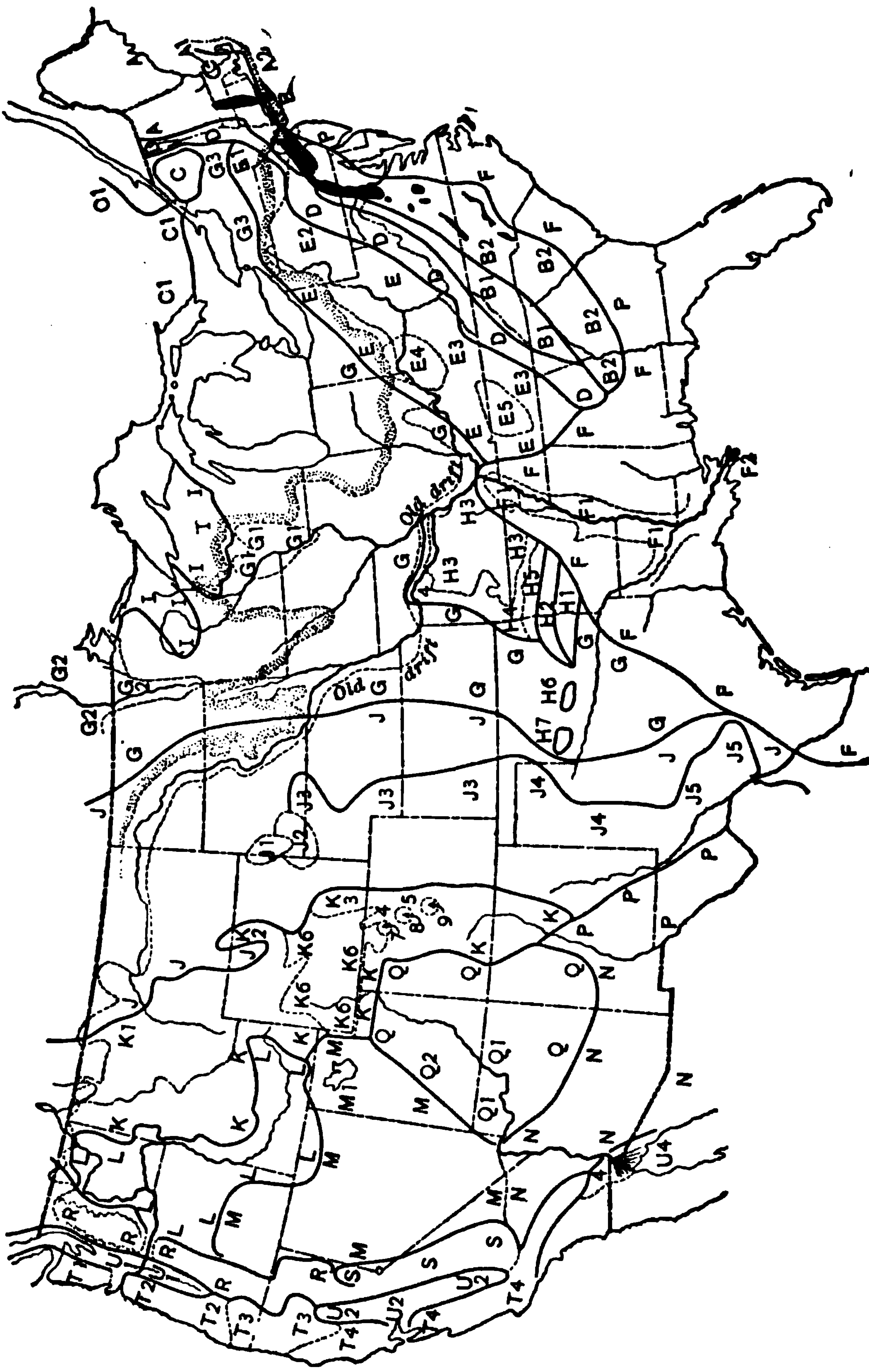


Fig. 50

calcareous shales. At Narragansett, A2, is an infaulted patch of coal-bearing shales. Both of these have conditioned a flat, low-lying country whose principal relief is due to hills of glacial drift. Two great north and south valleys, the Connecticut and the Housatonic, have developed along the strike of belts of weak rock downfaulted into the crystallines. The Connecticut valley lies for 100 miles, on a belt of shales and arkoses, dipping eastward, striking north-south, and so developing long, low ridges and flat, wide valleys. Rising above this level are intrusive and extrusive sheets of diabase, which develop striking north and south ridges, locally called mountains, such as the Holyoke Range. These are a great source of trap; brownstone is quarried from the arkoses (see Fig. 50, black area). The Housatonic valley is an infaulted belt of limestone, and, like the Connecticut, has developed a flat, broad lowland between high ridges of crystallines. It is an isolated part of the Newer Appalachians. The soils of New England are mainly glacial. Several minor moraines cross it, drumlin areas and kames are common, and boulder till is the widespread sheet soil. Along the Connecticut and Housatonic and their larger tributaries, alluvial soils dominate, and very notable clay and gravel terraces are developed. Swamps and ponds are extremely common.

The Older Appalachians, B, are continuous with the western New England Highland, and consist of crystalline schists, gneisses, marbles, and plutonic igneous rocks. They form a rolling country which is rather sharply divided into two levels, a higher level, B1, forming the Hudson Highland and the Blue Ridge country of the south, and a lower level, B2, forming the Piedmont Plateau. The strike changes where the rock crosses the Hudson River, from north and south to northeast and southwest. All the granite quarries in the eastern States, south of Storm King on the Hudson River are in this province. Being the oldest rocks, they are in places covered up by younger sediments, which break the continuity of the province. From eastern New Jersey southwestward a series of red and gray shales, arkoses and conglomerates, like those of the Connecticut valley, occupy a down-warped basin covering the Piedmont crystallines (see Fig. 50, black area). These sediments weather into a broad lowland diversified by low ridges of sandstone, quarried for brownstone. The sediments are cut by great intrusions of diabase, and include several surface-flow sheets of basalt, most of which strike and dip with the sediments. They form prominent ridges, breaking the lowland. The Palisades intrusive is a great source of trap rock. Soils in the northern part are glacial, including many lake and terrace deposits, the source of excellent brick clay; but south of the glacial limit, deep residuary soils, grading into alluvial soils in the valleys, are dominant.

The Adirondack Mountains, C, are a part of the Laurentian oldland of Canada, C1, consisting of gneisses, schists, and marbles cut by granites, syenites, and gabbros. The western portion is a rolling upland of rounded hills and deep valleys, all glaciated. The eastern part, higher and more rugged, is a group of fault blocks whose very steep valleys are formed by erosion along fault lines, and have a pronounced trellis pattern (see Art. 15). The highways follow these valleys, and so are built upon talus slopes, alluvial bottoms, and along terraces formed at the close of the glacial period.

The Newer Appalachians, D, lie west of the Older Appalachians and consist of shale, sandstone, limestone, and conglomerate in the order of abundance named, overlying the crystallines of the Older Appalachians. Igneous rocks are almost wholly absent, but quartzite, bluestone in New

York and Pennsylvania, and limestone are quarried. The strata are folded in long, parallel, pitching folds striking 20° to 40° east of north, but turning nearly eastward in Pennsylvania. The eroded edges of the sandstones and conglomerates form the mountains, paralleled by stream valleys on shales and limestones between parabola-shaped ridges (see Fig. 32) and are developed on many pitching folds. All folds are overturned toward the west (see Art. 16, Fig. 60); they are very often faulted, typically by a fault lying parallel to the fold axis, with the eastern limb upthrown (see Fig. 60). The streams have developed a very striking trellis drainage pattern (see Art. 15, Fig. 57). The larger streams cut gaps thru the mountains along which all important highways of the province pass. The easternmost rocks of this province, just west of the Older Appalachian crystalline belt, are shales and limestones of great thickness, complexly folded. These have weathered out into a fertile valley 30 miles wide, which follows the strike of the rocks thru New York south to Alabama, and is called the Great Appalachian Valley, D1. The valley is not drained by one river, but by a number of separate streams, among them the Hudson north of the Highlands, the Shenandoah, Cumberland, and Tennessee. Soils are mainly residual, varying with the bed-rock. Alluvial soils occur in the large stream valleys, but are of limited extent as compared with the flood-plains of equal streams in the Plains Regions. Glacial soils are common in the northern part, where extensive terrace and lake deposits furnish brick-clay, sand, and gravel.

The Appalachian Plateaus, E, lie west of the Newer Appalachians, and are simply the same rocks, without the folding. The folds of the Newer Appalachians die out westward, leaving the rocks horizontal (see Art. 10, Fig. 28). The plateau has developed a bold scarp which looks down upon the ridges of the folded Appalachians to the east, and is called the Allegheny Front, Cumberland Escarpment, etc. The province includes the Catskill mountains, E1, a mass of sandstones, conglomerates, and shales; the Allegheny Plateaus, E2; the steep, rugged hills of West Virginia and eastern Kentucky, which are simply a plateau strongly dissected; the Cumberland Plateau, E3, in Tennessee and southward. All these members have nearly horizontal strata, shales, sandstones, and limestones. A few low anticlines have brought soft limestone to the surface, whose weathering has developed a rich clay-covered lowland surrounded by the high, sandstone-capped plateau. These depressions are the Blue Grass Country of Kentucky, E4, and the Nashville Basin of Tennessee, E5. The northern part of the province has been glaciated, and here till is the dominant soil.

The Coastal Plain, F, begins in Mexico, bordering on the Gulf of Mexico. It crosses the Rio Grande about 150 miles from its mouth and continues as a broad belt around the Gulf, narrowing up the Atlantic to Long Island, beyond which its continuity is broken, and only isolated patches of its rock appear. The rocks are soft shales, clays, sands, gravels, and limestones, the last increasing southward. The beds dip very gently seaward, so that the harder ones develop low cuestas facing inland. The stream pattern is dendritic and all the valleys are broad and open; the general country is very level. As these rocks overlie the Piedmont crystallines, the rivers develop rapids in passing eastward from the Piedmont to the soft coastal plain rocks, and the interprovince boundary is, therefore, called the Fall Line. Philadelphia, Raleigh, N. C., Camden, N. J., Columbia, S. C., Augusta, Ga., Macon, Ga., Columbus, Ga., Montgomery, Ala., Tuscaloosa, Ala., are important cities located on rivers at the Fall Line.

The Atlantic Coast as far south as Cape Hatteras has been recently submerged and then slightly re-uplifted. Submergence, therefore, conditions that many river valleys have been drowned, making bays. The Hudson and Delaware Rivers, and Chesapeake Bay are striking examples. Bars of sand have built up outside the ragged coast line, enclosing the bays. Many rivers have tides. Salt marshes fringe much of the coast, and the recently uplifted part of the sea bottom from Maryland south has many swamps and lakes.

The Alluvial Plain of the Mississippi, south of Cairo, Ill., is 20 to 50 miles broad and 600 miles long excluding the Great Delta, F1, F2, whose greatest length is 150 miles. It is bordered by steep bluffs, the eastern ones capped by loess. The valley is a flat, swampy lowland of sand, silt, and clay soils, occupied by countless oxbow lakes and their swampy remnants; crossed by low ridges, the natural levees of present rivers and abandoned channels. These and a few long strips of the original upland of the region form the natural highway. The average fall of the river is about 1.2 ft per mile. The entire lowland is subject to occasional floods, due to breaking of the natural levees, but the levees are being strengthened, banks protected and swamps drained, so that floods are now far less frequent and destructive than formerly. Sand-clay roads, commonly built upon the natural levees, are the dominant type.

Soils of the Coastal Plain. (1) On Long Island two terminal moraines form east and west lines of hills. The flat southern plain is outwash, beyond which are wave-built sandbars. (2) Residuary soils, chiefly clayey loams, cover the rest of the plain, except (3) and (4). The limestone areas have developed rich, sticky, residuary clays, as in the Black Prairies of Georgia, Alabama, and Mississippi. (3) The Lafayette formation overlies the Plain over areas aggregating 200 000 sq miles. It is dominantly gravel and sand in the valleys, clay and silt on the divides; usually a light, porous loam. (4) Overlying the Lafayette, or sometimes resting upon the Plains strata, is a finer sand and silt called the Columbia formation; usually forms a porous, fertile loam, seldom over a few feet thick; occurs only along the Atlantic Coastal Plain.

The Prairie Plains, G, lie between the old Lake Superior-Canada crystallines on the north, the Coastal Plains and Ozark Uplift on the south, the Great Plains on the west, and the Appalachian Plateau on the east. The boundaries are indefinite. The rocks are all sedimentary: Shales, much limestone, and some sandstone; the last two are the most serviceable for all purposes. Conglomerates and crystalline rocks are almost wholly lacking. Glaciation reaches its fullest expression here. The older ice invasions have left sheets of now deeply dissected boulder till, separated by layers of peat, lignite, and stratified drift formed in interglacial periods; but the last two advances have built the moraines (see Fig. 50, broad dotted streak), and only within the area covered by these ice sheets are found the lakes, swamps, drumlins, kames, and other conspicuous topographic expressions of glaciation. The ice moved southward in the form of lobes or tongues, and so built loop-shaped lines of moraine around each tongue. As the ice retreated, halting at places, new loops were built within older ones. Kames of bedded sand, gravel, and clay abound both in and near the moraines. Great drumlin areas occur. Outwash plains, 1 or 2 miles wide, fringe the moraine. Myriads of lakes and swamps occupy depressions in drift. South of the terminal moraine, partly covering the older drift and the unglaciated areas, is a fine, compact, calcareous silt called loess (see Art. 8). Because it was largely wind-blown in a region of westerly winds, it is usually thicker in the valleys and on the eastern side of streams

and hills, averaging 10 ft thick, but reaching 60 ft or more. It is an important soil in western Illinois, eastern Iowa, and Missouri. It follows the Missouri and Platte Rivers, and the eastern bluffs of the Mississippi nearly to their mouths, weathering into vertical cliffs. Thus the soils are: (1) Glacial, boulder till, kames, drumlins, etc, including outwash plains; (2) lake deposits and shore deposits; (3) loess and dune sand; (4) residuary soils in the driftless area, G1, and the region south of the limit of glaciation; (5) the alluvial soils of the flood-plains of great rivers. Broad lake deposits furnish clay and sand soils; one extinct great lake, G2, lay in North Dakota and Minnesota and northward into Canada; the present Great Lakes were once larger and their old bottoms are bordered by shore beaches, long level ridges of sand and gravel, forming natural highways called ridge roads.

The Central Lowland of New York, G3, is a belt of weak rocks, shales, limestones, and less sandstone, striking east and west and dipping gently south. It forms a broad open lowland with low cuestas facing northward. The cuestas continue westward thru the Great Lakes region, forming the scarp over which the Niagara River falls. They are a source of crushed and structural limestone for western New York and beyond. The soils are chiefly glacial; many hundreds of drumlins have developed, especially in parts underlain by shale. The Finger Lakes are glacially deepened in river valleys dammed by moraines.

The Ozark-Ouachita Provinces, H, are a continuation of the Appalachian Provinces, reproducing all the dominant features of the latter. The Ouachita Mountains, H1, are folded mountains of sandstone, shale, and limestone, eroded to give parallel and zigzag ridges like those of the Newer Appalachians. The Arkansas Valley north of the Ouachita Mountains has a very similar structure, but the ridges rise to only 800 ft. The Older Appalachians are represented only by isolated patches of crystalline rocks like the Syenite Knob, Little Rock, Ark., and the granites, diabases and gabbros in the Arbuckle, H6, and Wichita, H7, Mountains. North of the folded series lies the Ozark Plateau, H3, capped by cherty limestones. The rocks were slightly updomed and then eroded to form a flat-topped uplift about 1500 ft above the sea. The almost horizontal strata dip slightly westward and southward around the dome, forming a gentle slope called the Springfield Plain, H4. The southern member of the Plateau is higher and more rugged, capped by thin sandstone. It is called the Boston Mountains, H5. The soils are chiefly residuary, and vary with the bed-rock. The chief soil of the Ozark Plateau is a very porous chert, derived from the limestone. Limestone is the chief road metal of the region; important syenite quarries are located at Little Rock.

The Lake Superior Highland, I, includes several irregular areas of old crystalline rocks, complexly folded and faulted; schists, gneisses, quartzites, slates, associated with granite, gabbro, diabase, and many other igneous types, both intrusive and extrusive. Erosion has reduced them to ranges of low hills. Glaciation has covered the lowlands with drift, so that over large areas, no bed-rock is exposed.

The Great Plains, J, are composed of sedimentary strata, which dip generally eastward very gently. The surface is not strictly a dip slope, but an erosion surface bevelling the strata nearly parallel to the dip. The surface slopes eastward from 6000 ft at the Rocky Mountain front to about 1000 ft, merging into the Prairie Plains and Coastal Plains Provinces. The rocks are shales, sandstones, and limestones, some of them only slightly indurated. The simple picture thus presented is locally modified as follows.

(1) Along the Rocky Mountain front the strata are abruptly upturned and the steeply dipping edges of hard sandstone and limestone form ridges called hogbacks, parallel to the Rocky Mountain Uplift. (2) The Black Hills, J1, are a dome of ancient granite and schist, pushing up the Great Plains strata. The eroded edges of the upturned hard sediments form hogback ridges running concentrically around the central dome. (3) The Bighorn Mountains, K2, are a long range of old crystal lines pushed up thru the sedimentary rocks, upturning them to form hogbacks along the eastern front. West of the range the plains continue until again upturned by other Rocky Mountain ranges. Near the mountain border in Montana great volcanoes have burst thru the plains, forming the Highwood, Crazy, and other mountains.

The chief soil types are: (1) Glacial soils only in the northern part, without a well defined terminal moraine; (2) loess along the Missouri and Platte Rivers; (3) sand-dunes covering 24 000 sq miles in central Nebraska and smaller areas occurring in Kansas; (4) residuary soils from broad clay shales and from sandstones; (5) alluvial soils along the large rivers. The light rainfall is the chief reason for the lack of forests. Upon the western part of the Great Plains sediments, lies a thick mantle of sand and gravel, stratified and in part cross-bedded, which was washed out upon the plains from the Rocky Mountain mass. These deposits cover enormous areas. Their surface lies several hundred feet above that of the Great Plains so they are named the High Plains, J3. They end westward at the hogback line, and eastward terminate in a ragged scarp, very much dissected, abruptly overlooking the Great Plains. The Llano Estacado of Texas, J4, is a part of the High Plains. Soil of the High Plains is very porous, sandy, and dry, subject to very rapid erosion by cloudbursts and floods, especially where there is little vegetation to hold the soil in place. Deeply gullied, arid country called Bad Lands, J2, are thus caused.

The Edwards Plateau, J5, lies in western Texas east of the Pecos River. Its surface continues that of the High Plains, but it is a true plateau capped by a limestone 500 ft thick. The plateau is deeply dissected and ends eastward in a ragged scarp looking down upon the prairie lands of Texas. West of the Pecos, blocks of the Edwards Plateau are tilted by fault movements, so forming a part of the Trans-Pecos Province. The plateau soil is residuary flint and limy clay, wooded only along streams.

Rocky Mountains, K, consist essentially of a series of north and south trending ridges caused by upwarping of great anticlinal folds of old crystalline rocks, granites, gneisses, and schists. The Laramie, K3, Front Range, K5, Medicine Bow, K4, Bighorn, K2, and some other ranges have their steeper slope to the east, and here the excessive upwarp has caused the fold to pass in places into great upfaults. The Great Plains strata were steeply upturned by these uplifts. Clearly the top of the uplifted range was formerly coated with the Great Plains sediments, and some mountain blocks still retain remnants of them. The sediments are found on the gentler western slopes of the Bighorn, Laramie, and Medicine Bow ranges, and form extensive lowlands of essentially Great Plains type west of the ranges named. Some of the northern ranges, like the Lewis and Livingston, consist themselves largely of sediments, quartzites, slates, limestones, only slightly folded. The Lewis Mountains, K1, in Montana have been thrust eastward by great faulting, over and upon the Great Plains strata. Hence the latter are not upturned, and here there are no hogback foothills. The plains end abruptly at the foot of a mountain mass 4000 ft high. Some

parts of the ranges are largely made up of surface flows, like the rhyolite plateaus of Yellowstone Park. Separating the northern ranges are deep valleys, at least partly due to faulting and erosion along fault-lines. They are called trenches. Most have been somewhat deepened and remodelled by glaciers. They trend north and south, but some run into others, and streams find a way east and west thru gaps in the ranges, so that all drain east or west. The valley systems thus form the natural highways.

Road Maintenance is rendered especially difficult by the fol owing conditions, which are not uniform, but may occur in any combination: (1) Lakes, usually retained by drift dams, occupy many depressions in the valleys. (2) Streams all have steep gradient and may flow (a) perennially, when fed by seepage or heavy rainfall and when flowing on impervious bottom; (b) intermittently, if small, or in arid regions, or upon porous bottom. (3) Tributaries build deltas or alluvial fans out upon the floor of the main stream, sometimes even damming up the latter. (4) Ground water sometimes saturates the soil to the surface, forming soft peat swamps called muskeg. Seepage in the soils on the slopes is sometimes so great as to form patches of muskeg high on the slopes. (5) Soils on the slopes are always creeping and landslides of great magnitude are not uncommon. Cutting away some of the creep material above a road, perhaps cutting it back in terraces, or building a retaining wall against the cut bank, may render the mass more stable. Besides the sliding of matter from above, the roadbed itself may be carried downhill slowly by creep or rapidly by sliding. In either case, some parts will move faster than others, disjointing the roadbed. There is apparently no cure for this trouble if the road must be built on talus slopes. (6) Great variations in stream flow and ground water level are to be expected, and these will increase the chances of sliding, besides directly damaging the roadbed.

Enclosed between the ranges are a number of open, level regions called PARKS, K7, K8, K9, and others not shown in Fig. 50. They are floored in part with soft sedimentary rocks and in part with waste washed down from the mountains rising abruptly around them. The patches of Great Plains strata enclosed behind ranges such as K6, may possibly be analogous in structure to the parks. The surface of K6, called by Fenneman the Rocky Mountain Basin, is only relatively smooth, being broken by many crystalline masses rising thru the sedimentary floor. Alpine glaciers have carved the crests of the higher ranges as far south as northern New Mexico, forming: (1) Sharp, angular Alpine peaks; (2) deep bowl-shaped basins at the glacier head on the mountain sides, most of which basins now contain lakes; (3) deep, steep-sided U-shaped gorges where glaciers descended stream valleys; (4) tributary streams which usually enter the main valley high up on the wall, cascading down to the valley; (5) moraines and long trains of outwash in the glaciated valleys, which are now often occupied by lakes.

Columbia and Snake River Plateaus, L. Upon a rugged part of the Rocky Mountains, composed of schists, gneisses, granites, and old lava flows, there poured out a great succession of surface flows, chiefly basaltic, with some rhyolite, until all the lower ranges were buried beneath the lava floods, the higher mountains rising like islands above them. The flows did not all occur at once, but long periods of quiescence permitted lakes to form on the lava surfaces. Thus sand and clay, as well as ejected ash beds, lie between lava flows, and in these marked seepages occur. The Snake and Columbia Rivers have cut gorges from 100 to 6000 ft deep thru the basalts and, in places, thru the older crystalline rocks below. The basalt shows marked columnar jointing and weathers out in vertical cliffs with flat, level tops. The plateau surface is as a whole very level, but is broken by gorges cut into it, and by local folds in the basalt, forming hills, and by mountains of the old crystallines rising above it. The most conspicuous of these are the Blue Mountains, formed of old, strongly

folded sediments, cut by great masses of igneous rocks. The deep carved valleys are floored with alluvium.

The soils of the plateau region are: (1) Volcanic ash and dust, very porous, varying in thickness from a few feet to 500 ft or more, which forms desert soils; (2) windblown soils of very fine grain, somewhat like loess, making sharp contact with the basalt beneath, and varying from 25 to 50 ft in thickness; (3) floodplain and terrace soils along larger valleys, such as the terraces of the Columbia River, which are chiefly sand and gravel; (4) residuary soils upon the basalt in favorable places, which are dark, rich, rather light soils.

The Great Basin, M, is a region so enclosed as to drain inland into lakes, instead of draining to the sea. The rocks were broken by faulting into a number of uptilted blocks which trend generally north and south. In the Basin region proper these tilted fault blocks form very steep mountain ranges down which course rapid intermittent streams, building alluvial fans out onto the floor of the valleys. Broad, flat plains of sand and silt are thus built up, and many streams sink beneath the porous soil. Toward the north, the blocks are buried beneath the Snake-Columbia River lava flows. Toward the east and southeast the fault blocks are less tilted, and here form vast plateaus, which are the High Plateaus of Utah, standing one above the other, rising eastward to 9000 ft. They are separated by bold scarps, due more to differential erosion than to faulting. The Basin was once occupied by great lakes up to 1000 ft deep, of which Great Salt Lake, Provo Lake, Pyramid Lake, and many others in Utah and Nevada are remnants. The drying up of these salt lakes has left fine grained, alkali desert soils. The Great American Desert in Utah, M1, is the bottom of the greatest of these lakes. Beaches, bars, and deltas of gravel and sand mark the old shores.

Arizona Highlands. The block faulting of the Great Basin is repeated in the Arizona Highlands, tho on a smaller scale. The blocks trend northwest and southeast, continuing across the border into Mexico. The rocks are sandstone and limestone, resting upon old granites exposed by the upfaulting. Many of the blocks are capped by lava flows. Toward the northeast the sedimentary rocks increase, and the blocks becoming less tilted pass into the Colorado Plateaus. Rainfall is very light, and the soil is largely the products of disintegration (see Art. 6), washed into the valleys, which thus become waste-filled, sandy deserts.

The Trans-Pecos Highland, P, somewhat resembles the Great Basin and Arizona Highlands provinces, the ranges being chiefly tilted fault blocks trending a little east of north and rising 2000 to 4000 ft above a general lowland at about 3500 to 4500 ft. Volcanoes and intrusive masses also form conspicuous uplands. Soils are waste from the mountains rapidly washed down in time of freshet and either forming extensive flats of desert, or rolling country traversed by little canyons. Rainfall is very light, and forests lacking.

The Colorado Plateaus, Q, are a very complex group of large fault blocks which have suffered very little tilting. The rocks are sedimentaries of almost every type and aggregating over 10 000 ft in thickness, overlying ancient tilted sediments and still older granites and gneisses. The level-lying higher sediments form a series of plateaus separated by scarps developed by erosion along north and south fault-lines. Across these platforms the rivers have cut gorges, of which the Grand Canyon of the Colorado is the most famous. The plateau tops are very level, and are

diversified by volcanoes, surface flows, and their dissected remnants. North of the Grand Canyon, Q1, are a series of plateau levels standing one above the other, each higher member lying successively farther north. Each level is determined by hard capping sandstone, limestone, or basalt. This group constitutes the High Plateau of Utah, Q2.

The Cascade Range, R, consists of two distinct rock groups: (1) Ancient, complexly folded sediments, schists, quartzites, and limestones cut by many intrusive rocks, and dominantly acid. (2) Upon this mass, after uplift and deep erosion, great volcanic flows were poured forth, and a series of gigantic volcanoes were built, chiefly of andesites. Mounts Shasta, Scott, with Crater Lake, Jefferson, Hood, Adams, Ranier, and Baker are among the most famous of these, rising 3000 to 4000 ft above the older mountain mass. The entire range has been profoundly carved by Alpine glaciers, giving ragged peaks, deep U-shaped gorges and innumerable round, bowl-shaped glacier heads, now occupied by lakes. Northward into Canada the older rocks of the Cascade Range continue as a low, broad platform about 3000 ft high, lacking the younger volcanic rocks. South of the 40th parallel the younger series dies out also, but the old crystallines merge into the Sierra Nevada Range. The soils in the higher valleys are coarse and bouldery, becoming finer lower down and merging into the vast alluvial soils of the lower valleys (see PACIFIC VALLEYS). The rainfall is 60 to 150 in per year. Three-fourths of it falls between November and May; hence the Cascades are densely wooded.

The Sierra Nevada Range, S, runs from about the 40th parallel south to about the 35th. It is a block of complexly folded mica-schists, clay slates, and limestones, striking generally north and south, invaded by vast masses of granites. After uplift and erosion, surface flows, chiefly of andesite and basalt, were poured out, filling the river valleys and diverting the streams. The block was then uplifted along a great fault at its eastern base, thus developing a steep scarp facing eastward over the Great Basin, and a gentler slope westward, down into the Great Valley of California. The block is over 300 miles long, 25 miles broad, and about 9000 ft high. With the uplift, the main streams deepened their valleys into canyons and glaciers descended from the higher peaks and scoured the upper parts of the main stream valleys to U-shaped troughs, such as the Yosemite, Tuolumne, Yuba, Mokelumne, and Feather Rivers. The valley floors are seldom level, and their soils vary extremely in depth and texture. Roads follow the main valleys through the mountains, but it is often found that the deep, rocky gorges are less easy highways than are the ridges, which often are comparatively smooth.

Coast Ranges, T. The OLYMPIC MOUNTAINS, T1, south of Puget Sound resemble the Cascades. They consist of large volcanoes, built above a platform of old schists, which rise 6000 to 8000 ft and are densely forested up to 7000 ft.

South of the Columbia River lie COAST RANGES, T2, composed chiefly of sandstone, shale, and volcanic rocks, rising 1200 to 1700 ft, uplifted along a fault, with the steep scarp facing eastward over the Willamette Valley. They are cut into several units by westward-draining streams that cross them, forming important highway links between the valley and the coast. The intermittant uplift of the coast during mountain-building has given it a terraced form.

The KLAMATH MOUNTAINS, T3, are not parallel to the coast, but are a very complex group of ranges, some lying east and west. The group forms

a great platform, 2000 to 5000 ft high, sloping generally seaward. They cut off the Willamette Valley from the Sacramento, and abut against the Sierra-Cascade Range, from which they are separated by a narrow, tortuous valley, used as a railroad highway, between the Great Valley of California and the Willamette. The rocks are schists, limestones, and igneous rocks complexly folded and faulted, resembling the structure of the Sierra Nevadas. The entire region north from the Klamath Mountains lies in the belt of westerly winds and so has a very heavy rainfall. Dense forests, full rivers, swampy valleys, etc, are important correlated features.

The COAST RANGES OF CALIFORNIA, T4, are not quite parallel to the coast, but trend more west of north than does the coast. Thus they are successively truncated against the coast line, forming a series of promontories, the valleys between them forming bays, among which are San Francisco, Monterey, and San Luis Bays. The mountains are chiefly sandstones and shales, uplifted along great fault-lines. The most prominent of these is the San Andreas fault, or rift, traced as a marked depression for 190 miles. Movement is still in progress along these faults, causing earthquakes. The coast itself is terraced because successive uplifts have raised the wave-cut benches, but the most recent movement was downward. submerging some valleys. such as San Francisco Bay.

The CORDILLERAN VALLEYS, U, a series of valleys due, not to erosion, but to warping and faulting, separate the Cascade-Sierra Ranges from the Coast Ranges. Puget Sound and the Willamette River and smaller rivers occupy the northern valley, U1. More debris was brought down from the Cascades than from the lower coast ranges. The Columbia River crosses the valley to the ocean, cutting thru both Cascade and coast ranges. The rocks of the valley are sandstones, shales, and associated volcanic rocks like those of the coast ranges. The soils are: (1) A series of alluvial fans built out from the mountain canyons, composed of coarse gravel and sand near the head, and of fine silts farther out on the slopes; (2) colluvial talus slopes along the mountain foot, chiefly on the coast range side; (3) extensive flood-plain, delta, lake and even marine deposits, chiefly of fine grain, on the valley floor; (4) glacial deposits.

The GREAT VALLEY OF CALIFORNIA, U2, is due to faulting and warping, by which the coast ranges and Sierras were upraised about the depressed area. It is about 400 miles long by 50 wide. San Francisco Bay connects the valley at its middle point with the ocean. North of the bay, the Sacramento River drains the valley, while the San Joaquin drains the southern half. Both streams empty into the bay. The streams descending the Sierra Nevada block have built their alluvial deposits forward, filling the valley from the east westward, and forcing both the Sacramento and the San Joaquin Rivers to the western side of the valley. The valley floor is thus a nearly level, alluvial plain. Extensive swamps border the river. The San Joaquin breaks into a number of channels in its swampy bed. Some of the Sierra streams have built a large fan, cutting off the southern end of the valley, which now holds the swampy Lake Tulare.

The VALLEY OF SOUTHERN CALIFORNIA, U3, is a long, triangular area, lying south and west of the San Bernardino Range, T6. A low mountain range, the Santa Ana Mountains, T8, divides it into a seaward coastal plain and inner valley about 300 ft above sea level, deeply covered with fine alluvium from the San Bernardino and other mountains. The climate is dry and hot, and the stream volume variable. Still farther south, beyond the San Jacinto Mountains, begins another great valley submerged south-

ward to form the Gulf of California. The Colorado River has built a great delta of fine silt across the northern end of the Gulf, enclosing a salt lake which has almost dried up, forming the Salton Sink and Imperial Valley, lying below sea level. The shifting of the Colorado River across the delta caused flooding of the Imperial Valley in 1891, and from 1905 to 1907 the river broke thru to the valley several times along irrigation canals. The chief difficulties are offered (1) by the peculiar topography, a great river discharging across the conical surface of the delta fan, (2) by the fineness of the silt, and (3) by the absence of bed-rock. Southern California lies in a belt of light, variable winds, and hence lacks a heavy rainfall, except in the winter. The soils are largely alluvial, washed from the mountains and built out as fans into the valleys, hence coarsest near the mountains, where too the ground water level is deepest. Some of the valleys are rather swampy, but as a rule this is not met with south of the 35th parallel.

MAPS

15. Use of Topographic Maps

Contour Maps are issued by the U. S. Geol. Survey. For each state an index map is printed, showing exactly the areas for which topographic sheets have been issued. The maps can be obtained from the Director of the U. S. Geol. Survey, Washington, D. C., at a cost of 10 cents each.

The Scales commonly employed in these sheets are 1 to 62 500, nearly 1 in to 1 mile, contour interval 20 ft, 40 ft in some; 1 to 125 000, ½ in to 1 mile, contour interval 20, 50, or 100 ft; 1 to 250 000, ¼ in to 1 mile, contour interval 100 or 250 ft. Other scales are occasionally employed for special purposes.

The Canadian Geol. Survey issues an admirable map, 1 to 62 500, in 25-ft contours, in three colors. Large scale contour maps, topographic and geologic, are issued with reports on isolated districts of special interest. Many of these sheets can be had separately. Maps without contours, on the scales of 100 miles to 1 in and 3 miles to 1 in are available for large areas.

Fig. 51

Profile Plotting. It is often necessary to plot a profile along the route of proposed highways, showing the slope of the land. Method. (1) Figure out the relation between the horizontal scale and the contour interval. If the contour interval be 20 ft, and the scale 1 to 62 500, the space to allow on the profile would be figured thus: 20 ft = 240 in. 240 in scaled at 1 to 62 500 = 240 ÷ 62 500 = 0.0038 in. Or, 240 in in nature equals 0.0038 in on the map at the scale stated. 0.0038 is about 0.004, or about 1/25 of a space on 1/10 in coördinate paper. (2) Lay out on the map the line along which the profile is desired. (3) On a piece of coördinate paper, 1/10 in is most convenient, choose a horizontal base-line at about the lowest altitude encountered along the profile. (4) Lay the coördinate paper along the plotted line, and bring down the points where the contours cross the line, as indicated in Fig. 52. Place a dot exactly in line with each contour at a

height above the base-line proportionate to the altitude of the contour-line. (5) Connect these dots by a continuous line. In Fig. 51, the interval is 100 ft, and the scale 1 to 125 000, hence the assigned vertical space per contour interval = 0.0096 in, or about 0.1 of a space on coördinate paper. It is often convenient to exaggerate the vertical scale to render the slopes more easily visible. This can be done by multiplying the equivalent of the contour interval, 0.0096 in in Fig. 51, by any convenient factor. A proportional divider is a most convenient instrument to use for this work. To avoid excessive distortion (see Fig. 51, 2), the horizontal scale may also be multiplied; measure the horizontal distance on the map between each two successive contours along the profile line, lay off this distance twice, three times, etc, on the coördinate paper as a horizontal distance, so that all contour-lines appear in the section twice, three times, etc, as far apart, horizontally as they do on the map. Where the proposed highway line bends, simply place the paper in the new position, continuing the profile in the new direction exactly from where the old one left it. Mark the point of departure plainly by a vertical line and suitable legend.

Map Reading. The contours are crowded close together on steep slopes, and are wider apart on gentle slopes. The features that may be read from topographic maps may be grouped as physiographic and structural features.

Physiographic Features. The direction in which a river flows is indicated in two ways. The contours always bend up-stream in crossing the river (see Fig. 52A). In rounding a curve, the river always undercuts the outside bank, or concave bank (see Art. 11). It continues this undermining some distance down-stream along the same bank, even after the curve has been passed. The crowding contours show the steep undercut bank, and the down-stream prolongation of it points the direction of the flow (see Fig. 52, arrows). This method is especially applicable in reading maps on which no contour crosses the river in the entire length of river shown on the map. A meandering river, surrounded by a flat region, with very few contours in it, may be assumed to be a mature river with a flood-plain. Therefore, the soil is silt and sand with little bed-rock. If the river shows shoals, especially if its gradient is fairly steep, the water is muddy. Terraces are shown in the flat flood-plain area by the crowding of a few contours in lines somewhat parallel to the stream (see Fig. 20), especially in places just down-stream from a jutting promontory of hard rock. The terraces contain either clay, or gravel and sand, and may be worth while investigating, as well drained, convenient quarries can be developed here. Higher terraces are apt to be gravel, lower ones clay, but this is not a rule. In glaciated countries we find marked irregularities of drainage pattern, with swamps, lakes, and sometimes deep gorges where the stream, displaced from its valley by the glacier, has cut a new valley for a distance thru solid rock. Very numerous, irregular small hillocks, with irregular depressions, swamps and lakes among them, are morainal drift or

Fig. 52

till, and therefore deep soils. Fig. 53 shows a terminal moraine near Plainfield, N. J., in which the black areas indicate lakes, and dotted areas, swamps. The beginning of the outwash plain is shown by the simple contours along the eastern border. Flat-topped, low hills in the same region are delta kames. Drumlins are elliptical, smooth hills, all elongated in a parallel, nearly north and south direction, and not infrequently twinned, that is, two drumlins fused side to side. Swamps are always associated.

Fig. 53. Terminal Moraine

Structural Features. Strike. Ridges on the map are almost always elongated in the direction of the strike, and the ridges are of harder rock than the valleys (see Fig. 54). Dip. A dipping hard bed will develop a cliff along its upward projecting edge. See Art. 10, Fig. 28, *k*. The soft beds underlying it are washed out, undermining the hard bed and keeping it steep. A gentle slope develops on the dipping face of the bed, where the overlying softer sediments are washed off from the surface. Thus one is able to read the dip of strata on the contour map; Fig. 51 shows cliff A dipping west, cliff B dipping east. Folds may be read by observing opposite dips or by studying the parabolas traced by the outcrop of a pitching fold. See Art. 10, folds, Fig. 32; also Fig. 54 where A is an anticline, and B a syncline, both pitching south.

A B

A B

Fig. 54

Faults. The following criteria help one to read faults on a map. A cliff is abruptly offset. For instance, a north and south cliff will suddenly be discontinued in the direct line of the strike, but will be seen some distance east or west of the discontinued outcrop, and will continue in the altered position with a strike parallel to the first. The place of offset is the locus of a fault, and the upthrown block is set back, in the direction toward which the rocks dip (see Art. 10, Fig. 35). A valley cuts abruptly across the strike of the rocks, often cutting several parallel ridges. The valley may be developed on the weak rock in the fault crush zone, but such a valley does not prove faulting.

Fig. 55

Stream Pattern. In regions of horizontal strata, plains or plateaus, the same rock will form the floor over large areas. The streams therefore encounter equal rock resistance in all directions, and so develop a very symmetrically branched tree-like or dendritic pattern of stream arrange-

ment (see Fig. 55). Where either folding, tilting or block-faulting has caused a decided dip, the streams encounter alternate hard and soft beds. They tend to flow down slopes at right angles to the strike, and concentrate in master streams which flow, for the most part, parallel to the strike, and develop a right-angled trellis pattern of drainage system (see Fig. 56), as in the newer Appalachians. Thus the stream pattern suggests rock structure.

16. Use of Geological Maps

The U. S. Geol. Survey does not issue separate geological maps, but publishes with folios, bulletins, etc, colored maps showing areal geology, economic geology, soils, artesian water, and structure sections. Except the last, these are printed upon the topographic contour map. No special dip symbol is used.

Fig. 56

Horizontal and Vertical Strata. The outcrop of a horizontal stratum is parallel to the contour-lines; and like them, bends up-stream in every valley (see Figs. 57 and 58, AA*aa*). The outcrop of a vertical stratum may cross a stream valley without deflection, BB*bb*, and unless it be a markedly harder or softer rock, may cross the country independently of the contours. In stream valleys, a stratum dipping up-stream shows a V-shaped outcrop pointing up-stream, which is more broadly open than the V of the contour-lines, CC*cc*. If the dip is down-stream, the V-shaped outcrop points down-stream, DD*dd*. Gently dipping strata give broad outcrops; steeply dipping strata, narrow ones (see Fig. 59). If beds dip westward, higher, that is, younger, formations will be met with in going westward; the dip is always toward the higher beds.

Fig. 57

Fig. 58

The slope of the land will obviously vary the width of the outcrop independently of either dip or thickness. In level strata the width of outcrop is greater, the gentler the slope. If the dip is with the slope, the outcrop will be broader; if against the slope, narrower. It is always wise to attribute

Fig. 59

changes in width of outcrop to changes in dip and surface slope, rather than to change in thickness of the bed, for thickness is as a rule far less variable than dip and slope. In drawing structure sections, try to plot with constant thickness; this effort will serve as a good qualitative guide to the angle of dip. But the thickness is variable, and the entire map must be carefully searched for evidences of this variation. To determine the thickness of beds: (1) Simply plot the dip and width of outcrop upon an accurate profile of the surface. The thickness will be the distance across the bed, normal to the dip (see Fig. 59). (2) On a map or in the field, if the dip, surface slope and width of outcrop are known and (a) the land surface is horizontal; the thickness is sine of dip times width of outcrop; (b) the surface slopes with the dip, not necessarily parallel with the dip; the thickness is width of outcrop measured along the slope times sine of the difference between the angle of dip and the angle of slope; and (c) the surface slopes opposite to the dip; the thickness is width of outcrop times sine of the sum of angle of slope plus angle of dip. In constructing sections from U. S. Geol. Survey maps, this method is not applicable, as the dips are not given. But a thoughtful consideration of all the relations above set forth will enable the order of magnitude of the dip to be estimated very fairly.

Angular Unconformity is shown by abrupt divergence of strike, the patterns of two adjoining areas being markedly unlike. But confusion may arise, for such divergence may be caused in three distinct ways: (1) By stratigraphic unconformity, where an older series of rocks is overlain by a much younger series of different dip and strike, and both series are exposed at the surface. (2) By igneous intrusions, where an older series of sediments are cut by younger intrusive masses, whose exposure at the surface does not at all follow that of the sediments. But the shape of the igneous outcrop, as dikes, round necks or stocks, etc, appearing thru the elsewhere continuous sediments, gives a clue to this relation. Besides, the relative age of the intrusions is usually stated in the marginal legend of the map. (3) By faults, which bring together strata which do not match. These are always marked by some symbol upon the map. The upthrown side always brings lower, older rocks to the surface, over against younger rocks on the downthrow side (see Fig. 59). The character of a fold is most readily determined by means of the succession in which the beds outcrop across the map. Thus in Fig. 59 the succession is from higher beds at the margin of the fold, A, to lower at the axis to higher again, indicating an anticline.

To Plot a Structure Section (see Fig. 59): (1) Note the sequence or age of the rocks, as given in the marginal legend of the map. (2) Carefully study the entire map, determining the structure by means of all suggestive data, topographic and geologic. Note if any beds thin out or are missing from some one part of the map. Mark out in dotted lines the axes of folds, and show by arrows the inferred dips. Mark in some way the upthrow and downthrow sides of faults. (3) Plot a surface profile along the desired line of section. (4) Place a dot on the profile exactly where each formation outcrops along the section. (5) Plot in the inferred dips, and connect them underground, completing the inferred folds. Correct the dips, and depth of fold, if they are so drawn as to cause unlikely variations in the thickness of the beds. Test thickness by plotting at every outcrop, and, if the inferred thickness varies too much, look for possible errors in reading the dip.

QUARRYING

17. General Considerations Relative to Quarrying

The highway engineer may have to open and operate small temporary quarries for local supply during the building of a highway. In large contracts he may have to open and operate quarries for long periods of time, extracting structural material, crushed rock, paving blocks, curbing, etc. The requisites for successful work are: (1) Suitability of rock type and quality; (2) available quantity; (3) favorable conditions for extraction; (4) proximity of the quarry to the place where rock is to be used; (5) reason-

able cost of obtaining it, including (a) stripping of overburden, (b) disposal of waste, (c) length, grade, and methods of haul.

Structures Influencing the Development of a Quarry. The fractures traversing rocks may be summarized as bedding, lamination, flow structure, joints and sheet structure, and rock cleavage. The planes of weakness along which rocks may be conveniently split may be summarized as bedding, cleavage, reeds, rift, and grain. Fractures limit the size and shape of the blocks that can be extracted. Dimension blocks cannot be taken from a quarry having closely spaced joints, but such conditions are favorable to extraction of rock for the crusher.

INCLINATION. In horizontal or gently dipping rocks, the quarryman may select the beds he wishes to work, taking out thick or thin blocks as he pleases over large areas. The amount of material available is, in uniform rocks, practically unlimited. In steeply dipping rocks, all beds must be taken out, whether useful or not, with the risk of great waste if the beds are not uniform in quality. Or the rock may have to be mined out, a process too costly for the highway engineer. Other questions that must be considered in the field are as follows: How many beds possess favorable structure and quality? How long is the strike along which the quality does not change, the distance from the road become too great, the overburden excessive, property rights prohibitive of operation, nor the outcrop come to an end because a stream or a fault-line cuts it off? FOLDING, aside from its connection with dip, may limit quarry operations by bringing unfavorable rocks to the surface. Only a few suggestive examples can be given. Each field occurrence presents a distinct problem. In the anticlinal hill (see Fig. 60 modified from (7)), site A is bad, as the face will soon reach the infolded sandstone; site B is better than A, giving broader outcrop, gentler dip, and permitting easier methods of extraction. Displacement of rocks along a FAULT may bring some wholly unsuitable rock into the place of the workable rock (see Art. 10, Fig. 33). Such a quarry must end at the fault-line. Overthrust faults have often pushed unworkable rocks over upon the desired rock, and so increased the overburden (see Art. 10, Fig. 34). The shearing and crushing involved in faulting often renders impossible the extraction of structural blocks, but favors development for crushed rock. The extensive fault-shattering in many cement limestone quarries along the Hudson Valley does not prevent their being profitably worked. The rock may be weathered along a fault zone, and so be unfit for road metal. Or the fault zone may have been rehealed with some soft mineral, as calcite. The healed zone is often unfit for engineering purposes. Fault-planes are often favorable to landslides, and their presence thus adds to the danger of quarrying. See Art. 13. Other important general conditions are the topography, overburden, drainage, supply of water and power, availability and cost of suitable labor.

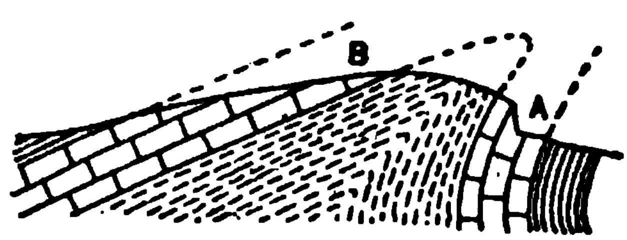


Fig. 60

18. Investigations Preliminary to Quarrying

Preliminary Studies. Neglect of thoro preparation for field work will inevitably cause loss of time and money in the field.

LITERATURE bearing on the region should be studied. Nearly every state in the Union has published a report on its stone and quarries as well as a general geological

map of the state. Most of these reports can be obtained free or at a nominal cost, by writing to the Director of the Geological Survey of that state. The U. S Geol. Survey has published a wealth of literature serviceable to the purpose. In both the state and national survey bulletins the names and characteristics of the individual quarries, or the rock conditions and quarries by counties, are cited and described.

GEOLOGICAL MAPS of the region should be studied and outcrops of favorable rock in favorable situations noted. Cross-sections, showing the structure, thickness, and relations of the beds, should be carefully prepared. Very commonly a large scale topographic map of a region has been published, but no large scale geological map. In this case, the general formation, sequence and character of the rocks can be read from the small scale geological map, and detailed structure, such as strike and dip, local folds, faults, etc, fairly well read from the topographic sheet. See Arts. 15 and 16.

The Tentative Plan of Operation of the quarry should be prepared. All of the preconceived ideas are to be held ready for modification when actual field studies are made.

Field Studies or Prospecting. In general, any steep hill other than one of glacial drift may be tentatively assumed to contain hard rock. The engineer must study the form of the hill and note any signs of its being merely capped with hard rock which protects a great mass of soft material below. The presence of water conveniently situated, the proximity of the hill to a line of transportation or to the highway on which the quarry product is to be used, are important factors in rapid preliminary selection (see Fig. 61).

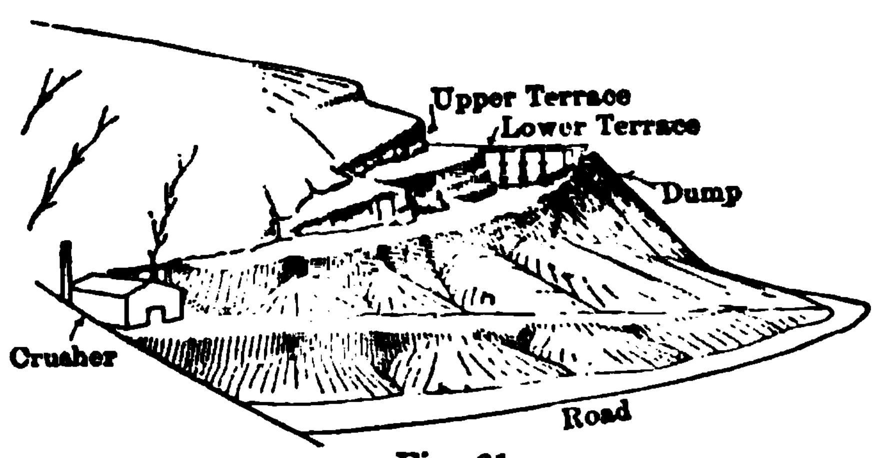


Fig. 61

The dip should be taken on all outcrops and plotted on a surface map. A cross-section should be constructed, to show the structure, succession and thickness of the rocks. Upon the plan, too, must be plotted the dip and strike of the joint systems.

As a practical suggestion of wide applicability, the following quotation is condensed from Snider (24): Another very favorable location for a quarry and crusher site: The top of the hill stands about 100 ft above the railroad track, and a little creek crosses the track at right angles just north of this hill. The bed of this creek would make an excellent location for a switch and for the crusher. The quarry could be operated by gravity and still have a face of 60 to 80 ft high, and a length of several rods.

Weathered Rock outcrops differ from fresh rock within the hill in the following features: Jointing, slaty cleavage, and tendency to check or split into chips are usually developed to a maximum on weathered outcrops. Rocks tend to split into thin sheets along the bedding planes. Harder and softer beds show up in strongest contrast. Chert, sand layers, and even clay layers, in limestone, being less soluble than the rock, stand out clearly. They are sometimes inconspicuous in fresh rock. Decay products of the rock can be fairly well judged. Especially in drift covered regions, one must be alert to distinguish boulders from outcrop. Boulders are usually somewhat rounded. Rock in place appears angular and jointed. Outcrops occur on the steeper faces, in beds of streams, and in artificial cuts.

The Fresh Rock within the hill may be expected to be more massive, less jointed and cracked, firmer and harder, and usually of darker color than on the weathered outcrop. Thicker and larger blocks are extracted as quarrying proceeds. This is not invariably the rule. If extensive de-

velopment for structural material is intended, core borings should always be taken and the samples subjected to petrographic examination and physical tests. Fractures and planes of weakness invisible in apparently sound rock may thus be detected. Test pits should always be dug to fresh rock, even when a temporary road quarry is to be opened.

The Cost of Core Boring varies with the type of drill used, the character of the rock, the depth of the hole, and many local conditions. Shallow shot-drill holes under 100 ft cost from $1.50 to $3.50 per ft. $3 to $6 per ft is a fair average.

Quantity Available. If beds are thick and of uniform quality, the dip will be the chief factor controlling the quantity available. If the rocks are horizontal or slightly inclined, the supply is practically unlimited. This is commonly the case in plateau regions, and in large igneous bodies like the Hudson Palisades, Maine granites, or the Columbia River basalts. In steeply dipping rocks, where the engineer does not intend to mine the rock, the quantity available will depend upon a complex of factors, as already indicated in the paragraph on dip. The uniformity, the thickness and the overburden are among the important factors.

A rock seen to be highly variable in quality in the weathered outcrop should be rejected, even if going farther entails more expense, unless some easily followed, massive beds promise enough supply for the purpose in hand, and better material lies at a prohibitive distance. Against the longer haul from a better quarry must be reckoned the very serious cost of excessive waste material in the variable rocks, the useless labor it entails, and the difficulty of disposing of waste. No rule can be given to guide the choice in such cases. The following suggestive paragraph is condensed from Snider (24), "The Hunton formation consists of an upper and a lower limestone and middle shale member. As it is usually steeply tilted, the differential weathering of these three members produces two narrow ridges and an intervening valley. Either of the Hunton limestone members would be suitable for road material, but as neither has a thickness of over 40 ft, and as it always outcrops near the Viola limestone, which is of good quality and 300 to 500 ft thick, the latter will almost certainly be used in preference to the Hunton." A simple device in the case of steeply dipping strata is to quarry along the strike, keeping to the outcrop of a favorable bed.

Overburden or top is the cover of soil and unusable rock above the workable stone. As it is rarely profitable material, the stripping must be economically done. A thick overburden sometimes cannot be removed, and the desired rock is mined out from under it. Thick cover, whether to be stripped or not, will prohibit quarrying unless: (1) The material mined is so valuable as to pay for the extra cost, as in cement or marble quarries; (2) the overburden is itself valuable, as for brick or lime.

Common overburden materials are sand, clay, soil, and tree stumps, glacial drift, weathered and broken bed-rock. Sandy soils are usually friable, but when mixed with clay are apt to be tough and hard. Glacial drift presents every variety of material from loose, friable soils to hardened boulder clay that will stand up in a vertical cliff when blasted, as in the Chicago Canal cut.

19. Operation of Quarries

Plan. It is important that a definite plan of development be fully decided upon before the quarry is opened, even tho it be a temporary opening. In any quarry: (1) The position and form of the working-face must be decided upon; (2) a place must be selected for a dump, and the methods of waste disposal be considered; (3) the floor should be so placed as to drain naturally, as water annoyances have closed many quarries; (4) all rock movements should be with gravity, down to the quarry floor, down to the crusher or dressing shed, down again to the transporting agency. If the quarry is to be a permanent enterprise, the form of the quarry when fully

developed must be minutely planned beforehand. For detailed descriptions refer to (5).

Location. Quarries should have hillside locations. Hill tops and level ground are generally to be avoided. In level land, the quarry is sure to develop into a pit-like cut in which water accumulates. On hillsides, the quarry floor can be so high that it will drain naturally; the waste and overburden can be dumped below the quarry floor level; the crusher, etc, may be further down the slope. See Fig. 61. The quarry is opened by (1) stripping off a convenient area of overburden, (2) securing a working quarry face. This may be done by blasting down the front of the rock cliff along the line that is to be the face, or by running a trench into the rock and then widening the trench. Graded approaches should be built with the first waste material. Stripping in small quarries is done with pick and shovel and crowbar. Wheelbarrows, horse carts, or small rail cars are used to transport the material. Blasting will be found economical in loosening tough or frozen soil. Deep blasts are commonly used when steam shovels are employed. The hand work costs an average of 25 to 30 cents per cu yd, but the cost is the resultant of many variable elements. It is advantageous to strip a considerable area at a time rather than to strip piecemeal as quarrying progresses. Stripping in permanent quarries is often done during the winter months, when regular work is suspended.

Dumping. Many quarries have been ruined by unwise methods of disposal of waste. The dump must not be placed so as to impede future development. Dumping down the quarry face is always bad practice. Waste may be used to build graded roads leading up to the quarry floor, the crusher, and to the main highway (see Fig. 61); or the engineer may decide in what direction he will develop the quarry face and then dump waste systematically at the opposite end. The amount of waste varies not only with the overburden, but with the method and purpose of the quarrying. In many smaller quarries for structural blocks the rock is loosened by blasting and the larger, irregular fragments are cut into dimension stone. This method is cheap, but wasteful, as less than a fifth of the quarried stone reaches market. Unless the smaller pieces can be used for crushed rock, they must be disposed of as dump.

Development of the Quarry Face. Greenwell and Elsden (5) classify quarries as (1) single face quarries with elevated floor, (2) benched quarries, with one face above another, (3) open pit quarries, (4) mines or underground quarries, and (5) combinations of any of these. Only classes (1) and (2) need be considered here. A large quarry face and a large quarry floor are desirable. The face may be extended along the strike as far as conditions of rock, topography, and property rights permit. A long quarry face has many advantages. The height should be moderate; 60 ft is convenient for easy and rapid extraction, and 120 ft should be a maximum in most rocks; but special conditions in large developments may make far greater heights advisable.

When the height is great it is well to work the quarry in terraces (see Fig. 61). Each terrace has its own working-face of convenient height. The top terrace is worked back into the hill, and the cutting-back of each succeeding lower terrace is so timed as to keep pace with the topmost. Many gangs can thus attack the quarry face simultaneously. The method is especially advisable in deep sand and clay quarries. Similarly, a very long quarry face may be broken into a series of short faces, each successive face being offset from the ad-

Fig. 62

joining face, as shown in Fig. 62. The chamber A was developed first, and is so worked as to keep always in advance of B, and so on. This is a very advantageous method, allowing many gangs to attack the face separately, and always exposing two free faces of rock for each unit of the quarry. In large quarries the two methods may be combined, as shown in Fig. 63. Some of the best organized quarries in the world are developed by this method. Fig. 64 shows a terraced quarry of amphitheatre pattern, with concentric terraces, each with a line of track leading down an incline to the quarry entrance. This type is used in developing large sand pits. The single face quarry developed along the strike is a very common type in road building, especially when the engineer has a portable crusher. Yet, tho this is one of the simplest types of quarry, all that has been said of choice and development of the site is applicable.

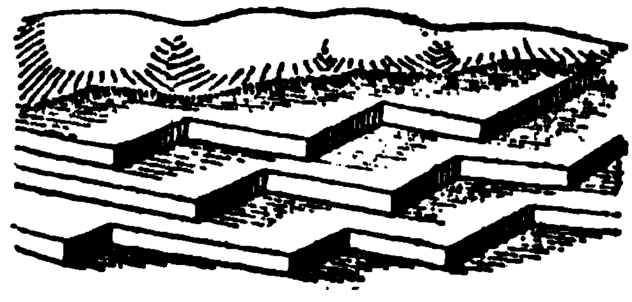


Fig. 63

In steeply dipping rocks it is often advisable to quarry on the dip slope side, so that the quarry face is the dip of the beds. Heavy charges of powder are put into holes at the base of the quarry face. The entire height of the rock face is loosened along the bedding planes, and slides into the quarry, leaning against the wall (see Fig. 65 (25). The loosened material can then be broken up by hand or by small charges, working at the bottom of the slide, which thus feeds down into the quarry until it is used up. In trap rock, the effective dip for quarrying purposes is the dip of the joint planes, and this is always apt to be steep. Blasting near the quarry face loosens up not sheets of rock but pillar-like columns that fall in blocks. As a rule it is not wise to face the quarry so that the beds dip into the hill from the quarry face, or where the beds overhang the quarry face, as shown in Fig. 66. This gives a very stable quarry face, but may require that rock be lifted out of its place against gravity. In very much fractured rocks, quarried only for broken stone, the dip is of less importance. There are temporary roadside quarries opened in a hard, silicious shale, in which the rock was so strongly checked that the dip could not be recognized. Another method is by undermining. Clay, sand, or soft rock is mined out from beneath a rock mass until the rock falls. Sometimes the undermined mass is jarred off by explosives as soon as cracks develop around it. This is a cheap method which has been used in England and France. It is used on a large scale in Saxony, but its use to cause large rock falls is dangerous. It is a very little used in America.

Fig. 64

Fig. 65

Costs. The range of cost in many plants is from 65 to 80 cents per cu yd. Crushed trap costs 75 to 95 cents per cu yd at the quarry.

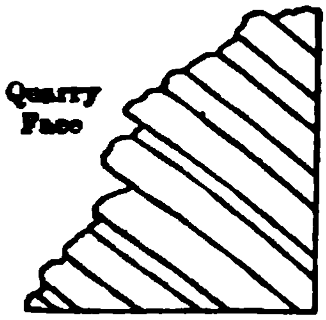


Fig. 66

Extraction of Dimension Blocks. The beds of a sediment, or the sheets of granite, must be thick and the joints widely and regularly spaced to permit the development of a quarry for dimension blocks. Only such methods as a highway engineer might have to apply in obtaining blocks for engineering masonry will be described.

1. The block may be worked out with levers and crowbars, if it be of convenient size and separated by joints from the parent mass.

2. The block may be far too large, or may be free only along certain planes. The simplest methods for splitting it off are: (a) By means of plugs and feathers

(see Fig. 67). The plug is a flat steel wedge P. The feathers FF are two pieces of steel cut as vertical sections of a cylinder, convex on one face and flat on the other. The feathers are placed in a drill hole, their convex surfaces fitting the hole, their flat faces together. The plug is driven between them, so as to push them apart. Shallow holes are drilled in the rock along the line of break desired, and plugs and feathers are placed in each. Great care is taken to set them perfectly parallel to each other, so that they all stress the rock in the same direction. The utmost care must be taken to drive the plugs with exactly equal force, using light taps all along the line. The rock splits off clean and true, with a f at face. Holes ⅝ to ¾ in in diameter by 2½ to 5 in deep and 6 to 8 in apart will split granite 6 ft thick. Such holes 2½ to 3 in deep will split granite 3 ft thick. Sandstone usually requires deeper holes than does granite. Holes in granite ⅝ by 2½ in can be drilled in 5 min. It takes about 1 min to set the plug and feathers. A good workman can drill and plug 80 holes in 8 working hr. With a pneumatic plug driller, 250 holes can be drilled in a working day. (b) A more wasteful, but much used method of getting blocks, is simply to blast out masses and sledge them into shape.

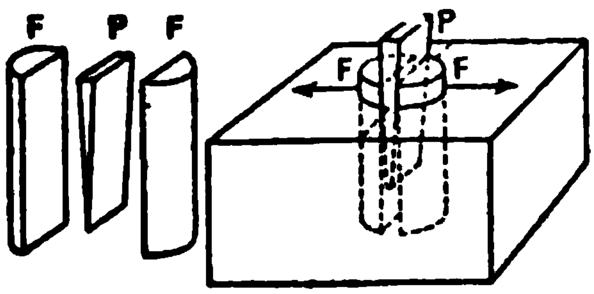


Fig. 67. Plug and Feathers

Bedded Sandstones and Bluestones split readily along bedding planes, giving flat plates suitable for flagstone. Thicker plates can be used for curbing or for structural material. The slabs are called lifts by the quarrymen. There a e usually two sets of vertical joints in a good bluestone quarry, one fairly parallel to the strike and called strike joints or side seams, the other intersecting nearly at right angles, and so called dip joints or headers. These, and the bedding planes, determine roughly the size and shape of the lifts. Quarried rock slabs often tend to split parallel to the bedding into thinner sheets; thus a stone quarried for curb may split into common flagstone. The plane of weakness along which the parting occurs is called a reed (see Art. 3, Fig. 17). When quarrymen wish to split a rock into thinner slabs, they select a visible reed and attack it with plugs and feathers, or simply with wedges.

In Granite Quarries there are usually at least three systems of joints, two nearly vertical and intersecting at various angles, and one approaching the horizontal, but often sloped parallel to the slope of the hill. This last jointing has a different cause, and is called the sheet structure (see Art. 10). The sheetings are usually closer together near the surface than at greater depths. The three joint systems divide the granite into blocks, which can be wedged or barred out, or loosened by judicious blasting and split with plug and feathers to desired size. Solid granite blocks are traversed by planes of weakness along which the rock may be easily split. There are either two or three sets of such intersecting planes c lled the rift, the grain, and the head, respectively. The rift is the plane of greatest ease of splitting, the head that of least ease. These planes are due to flat zones of gas or liquid inclusions in the quartz, and, to a lesser degree, in the feldspar, and to minute hairline fractures and faults that follow these zones. The rock can be split easily along these planes into flat-sided blocks, but an attempt to break a granite block in any other direction results in an irregular fracture. The rift is of utmost importance in the making of paving-blocks. A fairly fine grained massive granite with well developed rift and grain intersecting at right angles is required, and not all quarries yield such rock. The skilled workman can recognize the rift and grain directions, and by judicious, light blows with a sharp-edged hammer cleaves the rock into the required shape. The block must have four flat faces, so that a close-jointed pavement can be laid. Hence the rift and grain must form these sides (see Fig. 68).

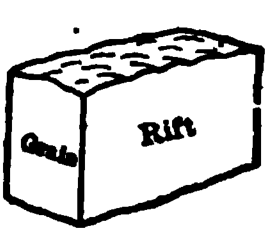


Fig. 68

Blasting should be done with black powder. High explosives are apt to shatter the rock, often leaving microscopic weaknesses even in apparently solid material. Road metal crushed from rock loosened by dynamite blasts is said to disintegrate more readily than when the slower explosives are used. Joveite explodes more slowly than dynamite, and penetrates farther into the rock. Its use is strongly recommended by Gillette (4).

Dangers. According to Greenwell and Elsden (5) more accidents in quarries are

due to rock falls than to any other cause. Carelessness in using explosives is the next most fertile source of accident.

Borrow-Pits. Flat lands usually have deep soils; hillside soils are shallower, and apt to be stony. Little gullies are apt to have thin and bouldery soils. In glaciated country, hills may easily be wholly made of drift; soil depths must be judged by recognizing sheet till, moraine, kame forms, etc. In all cases, if much material is needed, the depth may be explored by driving down a rod in several places until it strikes bed-rock or boulder.

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SECTION 4
PRELIMINARY INVESTIGATIONS

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LOCATION

1. General Considerations Relative to Location

A General Study of the Conditions underlying the proposed highway construction or improvement should first be made, and certain basic facts established as a foundation from which to proceed. If, for instance, the ways and means provided are for the general improvement of the traffic

facilities of a state, questions of location, as well as many others, may require different determinations than in the case of an appropriation for the construction or improvement of a single highway for the purpose of connecting two important points. In the former case, it will be advisable to take carefully into account the existing traffic facilities, such as railroads, and to avoid injury to their operations by too closely paralleling them with improved roads, thus duplicating the traffic facilities thru one narrow section instead of supplementing the existing facilities for traffic by the development of highways tributary to them, and thru territory lacking in sufficient ways for transportation. In the case of an individual highway connecting two two points it may, on the other hand, be most appropriate to strive for the utmost economy in both first cost and maintenance along lines identical with those underlying the economic location of a railwayunder like conditions. Similarly, different solutions of the questions as to location are possible within varying conditions surrounding the work. See Sects. 6 and 7, and Art. 15.

The General Principles Concerning the Locations of Highways are similar at least to those affecting the location of railways, and for an extended exposition of these principles, reference may be had to Sects. 6 and 7, and (12). As regards the selection of existing highways for improvement, which is the far more usual work of the highway engineer in this matter of location, the more general principles as are suggested above, and referred to as noted, will apply, and they should be recognized even more fully than they have been in many cases. It should further be always remembered that the limitations imposed by engines and cars running on rails are much narrower and more severe than in the cases of the more flexible vehicles using roads and streets. The latter find far less objection to undulating lines and grades such as may be desirable on a road for many reasons. For discussions in this connection, see (10), (21) and (22).

2. Lines: Curves and Tangents

Improvements in the Lines of Existing Locations should be made when practicable but with discretion. Hence, in considering the possibilities for such changes, certain facts affecting their desirability should also be considered. In the original location of highways and in the improvement of existing roads and streets, an unfortunate tendency has frequently existed for straight lines and right-angle turns at almost any cost. In urban districts, the disadvantages of one or both to the street authorities and to traffic may seem to be outweighed by the advantages to the adjacent property, but even this is not always really the fact, especially in residential sections where curved lines coördinating with or related to the contour lines may produce results infinitely superior to those from a rigid gridiron system. On roads, tangents and simple curves in the line are neither always desirable nor advantageous in the end. While tangents and right angles in highway lines may seem to be beneficial to the adjoining property because of the opportunity they give for placing rectangular buildings on the property with the least waste of ground, or for plowing in straight lines, their disadvantages, such as the tracking of vehicular traffic, the encouragement of improper high speed between turns, the danger to traffic at the sharp turns, the monotony of aspect, the excessive grading frequently required, and possibly other effects should be carefully considered. See (43a), (58c), (58d) and (58g).

Long Easy Curves, with even occasional reverse curves and a reduced

maximum curve, are almost always preferable on roads to tangents with a higher maximum curve at the turn between them, especially if other advantages, such as reduced grades, or better drainage, better foundations, better protection from wind and snow drifts, reduced maintenance cost, better shade and less danger to the traffic can probably be had. As regards turns, it should be remembered that while large motor cars can be turned without backing within a circle of less than 50 ft in diameter, and most, if not all, motor trucks, within one somewhat less than 80 ft in diameter, to do so requires more care and slower speed than it would be practicable to expect in rounding a corner in the highway. It is advantageous in establishing the line of a road to secure radii as much greater than 50 ft as practicable for the necessary turns and generally to make them not less than 150 or 200 ft. In this connection see Art. 15, (29d), (30), (57), (62) and (63).

Straight Lines on Roads should not ordinarily be secured at the expense of sacrificing trees or other like objects of value, unless a careful balance of considerations makes such a sacrifice necessary. The importance and value of trees and like growth for æsthetic, as well as for such ordinary considerations as shade, wind-breaks, effects on temperature conditions, etc, is just beginning to be appreciated. On the other hand, angles and turns should, as far as possible, be evidently necessary, that is, an apparent reason for them will do much to excuse their existence and forestall the otherwise ready objections to them. Other apparent reasons being lacking for an angle in the line, the making of it at an intersection will do much to relieve criticism.

Intersections must be investigated and considered most carefully especially in view of the recent and possible increase of speed general on highways. See (58c). Angular intersections, especially rectangular ones, are dangerous, particularly if the view from one highway to the other is in any way obscured. In such cases and where the number of vehicles crossing the intersection is great, police regulation of the traffic at the intersection is almost always a necessity in order that frequent accidents may be prevented, and if anything like effective use of the existing streets is to be had. If curvilinear intersections can be arranged, and what is known as the ROTARY system of traffic at the intersection approached or secured, not only will the dangers to the traffic be decreased and the necessity for police regulation materially diminished, but also the efficiency of the existing highways as such will be increased. See (43b). Possibilities for improving the location of the lines of the highways at the intersections should be thoroly examined. In this connection see (10) and (58c).

A View of the Importance of Proper Location compared with that of the other items of highway improvement may be had by reference to (29b) and (42). The authors point out that in expending borrowed money for highway improvement, the authorities in charge should distinguish carefully between the permanent and perishable features of the highway, and that alignment, drainage structures, foundations and grades should be looked upon as permanent features and expenditures for them in the light of investments. If these features therefore do not come up to certain standards, it will be poor economy to spend money on transitory improvements on top of them, such as surfacings, which must be maintained at considerable expense from year to year and ultimately be renewed, especially if considerable expense and trouble are gone to in making the surfacings as permanent as possible. The advocates of relatively permanent

surfaces contend that such crusts or pavements will have a considerable value as foundations for other surfacings after the expiration of their own life as a wearing surface. This is undoubtedly true if the alignment and grades of the highway are satisfactory at that time. Otherwise the old pavement will constitute a difficulty in the way of proper resurfacing and be a liability rather than an asset. The added cost of right-of-way in grading necessary to make the location the best obtainable may be offset to some degree by the value as a foundation of the old pavement at the expiration of its life as a surfacing. Hewes (42) gives as average figures from a study of 224 sections of road, the following division of cost:

Type	Drainage and Grading Percent of Total Cost	Paving Percent of Total Cost
Gravel, 20 ft wide	41.15	58.85
Water-bound macadam, 15 ft wide	36.89	63.11
Bituminous macadam, 15 ft wide	26.85	73.15

The importance and desirability in any case of increasing the percentages in the first column of figures and decreasing those in the second column of the above is evident. Especially will this be the case where the funds provided are borrowed because in that case the expenditures are really from the community's CAPITAL. If the expenditures are made from the annual tax levies, they may be said to be from the community's INCOME. The greater importance of expending capital for only those investments which may be regarded as permanent and profitable, and the desirability of confining expenditures for transitory benefits to incomes, each in so far as may be practicable, needs no argument here.

3. Availability and Character of Materials

The Comparative Availability of Suitable Materials for the foundation or the highway structures will, where opportunity offers a chance, affect the general location or the particular location of a section of highway. The location of a road along one side of a valley where suitable stone for its crust is readily obtainable is likely to be preferable to a location disadvantageous to such sources of supply. Other things being equal, the location of a road over a stratum of gravel or sand will be preferable to its location over clay or over a bog. Consideration of all such matters is necessary and important.

The Character of the Materials Available for construction will necessarily have to be known and studied in order that wise decisions in their selection or avoidance may be made. Records of tests will often be available, as in the cases of broken stone from established plants. In other cases especial tests may have to be made on the materials being considered, before proceeding further with some of the preliminary considerations.

4. Æsthetics and Local Environments as Affecting Location

Appearances and Suitability to Local Environments have often been given too little consideration in the determination of the locations of roads and streets. Later the value of proper consideration in such matters has become manifest and the lack of it been regretted. Frequently then it has been

too late to re-arrange the location satisfactorily except at prohibitive expense, and hence it is important that preliminary investigation should comprise special consideration on these points. See (58g). As angles in the location should be made at intersections, or because of some evident reason for the break in the line, such for instance, as a permanent object like a ledge outcrop, a hill, or, it may be, even a large and valuable tree, the existence of such reasons for angles should be carefully noted. Generally speaking, the greater satisfaction with a location properly made with consideration of the æsthetic features as well as of the other controlling matters is well worth the relatively small additional cost of including a proper consideration for appearances. See (58g).

Local Environment should be given proper consideration as to details of location. The proximity of a stream liable to sudden floods and departures from its regular channel may necessitate considerable expense for the protection of the highway and a location farther away from the stream, even if the curvature and the length of the highway be somewhat increased, may be preferable. A change in the location of a highway may necessarily accompany an improvement in grade if a spring or other feature of importance is to be protected, or if entrances from the highway to private property are to be properly provided. The general character of the lines of a road or street may be materially affected by the character of the development of the adjacent property. Curved locations are frequently more adapted to residential sections than to commercial districts. Consideration in this matter must embrace not only those of existing conditions but of probable or possible future conditions concerning the use of the adjacent property.

5. Climatic Conditions as Affecting Location

Climatic Conditions may affect the decision as to location where a choice is permissible. The avoidance as far as practicable of extremes of temperatures will reduce the effects on bituminous materials used in the construction of the road crust and the expansion and contraction in other materials. A location exposed to extremes of sun in summer and of cold wind and snow in winter it may be desirable to abandon for another less so but otherwise equally good. One location may be subject to greater and longer continued moistness than another and thereby be more or less desirable according to the character of the foundation, road crust and other considerations. The severity of frost action may be less in one location than in its alternative and this fact may decide between the two. The wind effects may vary between two otherwise equal locations and all these matters may materially affect the expenses for up-keep as well as for construction. For instance, on some poorly located roads, where alternative locations were appreciably possible, large amounts have to be spent each winter for removing or breaking thru snow drifts, when another location would have avoided this necessity. On some of the Cape Cod roads, located by force of circumstances in exposed positions, the State of Massachusetts, for a number of years, had to pay annually from $50 to $75 per mile for the spreading of sand on the roadway, in order to replace that blown away by the wind, and thus prevent the ravelling of the macadam.

6. Drainage and Foundations as Affecting Location

Drainage is often referred to as the most important single consideration in highway construction and maintenance, and as a general rule this is probably the case. Sect. 8 considers the matter of drainage in detail,

but the general importance of drainage and certain general principles must be kept in mind in the preliminary consideration as to location. Excessively wet locations should be avoided as far as practicable in order to save expense for both construction and maintenance. The same may be true under certain conditions as regards locations inclined to be unusually dry. Referenc to an article by Fearnside (33) will give an idea of the facts in this matter.

Opportunities for Drainage and the possible necessity for ditches, gutters and drains must be carefully investigated and noted in the preliminary investigations. Water comes to the highway in two ways, by the surface from storms or other temporary sources and by underground channels from adjoining land. Part of the storm water is prevented from reaching the roadway, and what falls on the latter is carried away from it by side ditches or gutters, the necessary provision for which must always be made. Side ditches and gutters may be simply concomitants of the crown of the roadway or they may be especial provisions for emergencies. Berm ditches, which are extra side ditches back of the edges of cuts, are frequently advisable to protect slopes in excavation from washing out or sliding and the need and opportunities for their provision should be investigated. One of the greatest difficulties in the actual construction and maintenance of highways is that of turning the storm or other water reaching the highway off from it, so as to provide efficiently for the proper drainage of the roadway. The property owners almost invariably insist on discharging, at their own convenience, storm and ground water and even waste water from their properties onto the highways, and this discharge increases with the development of the property. On the other hand, land owners generally object strenuously, and often effectively, to the discharge of storm or other water from the highway onto their property, except possibly at the natural water courses where running water is continuously present. The carrying of the storm and ground water from the highway itself along the highway to points where it can be disposed of, frequently necessitates expensive construction or high cost for maintenance. If to this water, drainage from the adjacent property is to be added, the expense referred to may be greatly increased. If the water thus to be taken care of can be frequently turned off the highway, it may be possible to take care of it much more efficiently than within the limits of the highway itself. The importance of careful investigations in this connection is great. For legal aspects of this subject, see Sect. 6, Art. 10.

Sub-Drainage covers the provisions made for taking care of the underground waters or for carrying water underground. In all cases where the road crust itself is built less than 2 ft above the level of the adjacent ground, it becomes necessary to consider the probable requirements for its protection, and that of its foundation or subgrade, from the softening effect of ground water especially when the level of the latter rises in wet weather to or nearly to the surface of the contiguous land. Underdrainage may be imperative and is provided by: Underdrains, open ditches and V-drains. The choice of method to be used in any case depends upon the conditions of the case itself and the proper pre-investigations regarding these conditions are important because of the possible effect of the decisions under them on the determination of the location as well as of the grades. See Sect. 3, Art. 12.

Foundations of the Roadway (see Sect. 8) must ultimately carry the load coming on the surface whether, by peculiarities of the road crust or pavement, the compressive strains are more or less distributed by the time they reach the subgrade. The supporting power of the foundation must there-

fore be sufficient, under the most unfavorable conditions likely to occur, to resist safely these strains. See (26g). Hence, in determining many of the questions preliminary to construction, it is desirable to note the character and competency as a foundation of the material over which the road crust is to be built; the possibilities of securing a better subgrade by a change in the location or grade; or the probable necessity for reinforcing the natural foundation where lines and grades will be fixed for other reasons. The conditions as to the foundations for probable structures, such as bridges and culverts along the line of the highway must also be investigated especially where there is considerable room for choice in the location of the roadway or its structure. In considering the naturally existing foundations, the effect of drainage on them, when it may be provided for their improvement, should always be taken into account. Questions of location may be affected by consideration of other details such as the character of the surfacing probably available for the roadway and the distribution of the strains on the foundation resulting from their passage downward thru the thickness of the road crust. See (56). The possibilities of arriving at an idea of the supporting power of the probable foundation materials by a mechanical analysis of the material with screens have been suggested and some researches were made along this line by McClintock in 1899-1900. The methods for this test have not been standardised nor has general agreement to the theories been expressed. The Mass. Highway Comm. has stated (54b) the following conclusion as a result of its experience:

"The Commission has estimated that non-porous soils, drained of ground water, at their worst, will support a load of about 4 lb per sq in, and having in mind these figures, the thickness of the broken stone has been adjusted to the traffic. On a road built of fragments of broken stone, the downward pressure takes a line at an angle of 45° from the horizontal, and is distributed over an area equal to the square of twice the depth of the broken stone. If a division of the load, in pounds, at any one point, by the square of twice the depth of the stone, gives a quotient of four or less, then will the road foundation be safe at all seasons of the year. On sand or gravel the pressure may safely be placed at 20 lb per sq in. Acting on this theory, the thickness of stone on state roads varies from 4 to 16 in, the lesser thickness being placed over good gravel or sand, the greater over heavy clay and varying thicknesses on other soils. In cases where the surfacing exceeds 6 in in depth, the excess may be broken stone, stony gravel or ledge stone, the material used depending entirely upon the cost, either being equally effective."

The same Commission speaking of SANDY LOAM as a foundation material said (54b): "Generally speaking, if 30% or more of the material will pass thru a 100-mesh sieve, the introduction of a drain does no particular good, the capillarity of the soil being so great that it will not give out the ground water. Under frost action the bearing-up properties are very poor, and the thickness of the covering will have to be increased until the weight is distributed over an area large enough to reduce the pressure to a safe limit."

In this same connection see the report of the Spec. Com. on Bearing Value of Soils Am. Soc. C. E. (15b). As regards artificial foundations, for an elaborate exposition of the theories underlying a formula for determining their thickness, see (64). See (26g), (28), (32) and (34).

7. Possible or Probable Changes in Conditions

Future Conditions cannot always be foreseen with accuracy, but in making investigations of existing facts, the possible or probable changes should be estimated and provisions made accordingly. It is upon the accuracy of such estimates and the sufficiency of the provisions made that the attainment of satisfactory results primarily depends. It may be assumed in

practically all cases that the improvement of a road or street will increase its importance, probably result in improvement of the property adjacent to a relatively high degree, and increase the amount and severity of the traffic to be carried by the road crust or pavement. Hence it seldom, if ever, occurs that a character of results which will just satisfy present conditions most economically will be satisfactory, or even efficient, within the early years of the life of such results. This principle applies to considerations of location as well as to the features of construction such as the surfacing itself and perhaps with even greater force because of the greater permanence of the location of a highway when once determined upon and formally established. Too much consideration of future conditions can hardly be given in all cases where the location is to be affected in any way by them and decisions, made along alternative or varied lines, are possible. For instance, an increase in amount or in the average speed of traffic may argue for flatter curves. The development of property along a road will materially increase the necessity for proper provisions for drainage, and hence, in determinimg the dimensions of the more permanent drainage structures and their location, careful consideration should be given to the probabilities of the improvement of the adjacent property.

The Maintenance to be Expected of Provisions for Drainage should be considered in this connection, because the location of proper inlets and their character as well as their size and the sizes of waterways generally will be materially affected by the character of the maintenance accorded the highway and its structures. If this maintenance is to be prompt and efficient, such as may be expected on many city streets, locations for the structures may be selected to meet peculiar conditions and a minimum size may be adopted for the waterways. If, on the other hand, the maintenance may be expected to be intermittent and inefficient, as in the case of many roads, every precaution must be taken to provide the most advantageous locations and sizes as well as character for the drainage structures so that their efficiency may never fall below a certain minimum. Some experienced highway authorities, more or less consciously recognizing the facts as above, lay down a rule that no pipe culvert under a roadway shall be built less than 12 in in clear diameter, no matter what the drainage requirements theoretically are, because of the likelihood of smaller sized pipes becoming obstructed. See Art. 10 regarding location of outlets at changes in grade. The decision as to the installation, in connection with the street pavement construction of catch basins or simple inlets may affect some decisions as to the pavement itself or the curbs. A catch basin must be so located and built as to permit its ready cleaning out at intervals. An inlet may not need such provision in its construction and the provision referred to may affect the location of the structure and the construction of the pavement surface adjacent to it. See Sect. 8.

GRADES

8. Consideration of the Effect of Grades

The Connection of Alignment and Grade is so intimate that their joint consideration is usually necessary. In such consideration, the exigencies of proper grades should generally be given preference as far as possible.

The Effect of Grades on Traffic should be given careful consideration, along with the other matters, to determine the limiting grades of a highway. A table, compiled by Herring (6), gives the results of experiments made at various times to determine the force required to overcome the resistance to the movement of a vehicle along horizontal roadways with different surfaces. See (7) and (9).

Reduction of Draft by the Improvement of the Roadway Surface. The following results of tests made on the Ames-Nevada Road in 1913-14 before and after improv

ment of the road surface are given by Smith (69). Draft to pull 1 ton: on Ames-Nevada Road (average both ways), all grades, black earth, before improvement, 106 lb, after improvement, 68 lb, average saving, 35.6%; on Ames Hill, grade 5%, sand, before improvement, 205.9 lb, sand clay, after improvement, 139.5 lb, average saving, 32%; on Ogden Hill, 9.6% grade, clay, before improvement, 274.5 lb, gravel, after improvement, 208 lb, average saving, 24.2%.

As the Effect of the Inclination is a matter of mathematical computation and may be figured from the formula: $R = F + aW$; where F = force required to draw load on level, a = grade expressed by a fraction, W = weight of loads in pounds, R = force required to draw load up incline in question; Table I gives the tractive force necessary to draw 1 ton over the best macadam on various grades and also the equivalent length of each mile of grade in miles of level road:

Table I

Rate of Inclination	Angle with Level			Tractive Force in Pounds	Equivalent Length of Level Road in Miles	Percent of Grade
Level	0°	0′	0″	38	1 00	0.00
1 in 500	0	6	53	42	1.10	0.20
1 in 100	0	34	23	58	1.52	1.00
1 in 80	0	42	58	63	1.66	1.25
1 in 60	0	57	18	71	1.87	1.33
1 in 50	1	08	16	78	2.05	2.00
1 in 40	1	25	57	88	2.30	2.50
1 in 30	1	54	37	104	2.73	3.33
1 in 25	2	17	26	118	3.10	4.00
1 in 20	2	51	21	138	3.63	5.00
1 in 15	3	48	51	171	4.50	6.67
1 in 10	5	42	58	238	6.26	10.00

The Effect of Width of Tire and Size of Wheels upon Tractive Power has been discussed by Baker, see (2).

The Effect of a Steep Grade in Reducing the Tractive Power of the Draft Animal is relatively much greater on an improved roadway than on an unimproved one, or, in other words, the load that can be hauled up a grade on an improved roadway is a smaller fraction of that which can be hauled over a level roadway of the same character than is the case where an unimproved roadway is the one being used. See (8).

McCormick (50) has compiled and presented some interesting data from studies of the effect on the draft of road surfacings, grade, width of tire, and methods of hitching and adjusting harness. The results show that the increased draft required for starting a load varies materially with the character of the roadway and that this increase is relatively greater on the harder tires; that the width of tire constantly affects the draft tho this effect may vary with different kinds of roadways; that the effect of grade is independent of the road surfacing but that relatively it is greater the harder and smoother the roadway.

For further discussion of resistance to traction, see Sect. 6, Art. 6, and Sect. 24, Art. 10, and also (2), (6) and (8).

9. Establishment of Maximum and Minimum Grades

Maximum Grades should always be established and then departures outside of these limits permitted only in extreme cases. Local considerations such as topography, character of highway, and nature of traffic, will affect the decisions. The smoother the roadway surface, the lower should be the maximum fixed. Maximum grades commonly established vary from 4 to 9%. The Act of Congress in 1806, providing for the construction of a National Road, fixed the maximum grade across the Alleghany

Mountains at an inclination of 5° from the horizontal, 8.94%. The following maxima are permissible for the different surfaces mentioned when the latter are properly constructed.

Gravel	6 to 10%	Sheet-asphalt	3 to 5%
Broken stone		Asphalt block	6 to 8%
Brick	4 to 6%	Wood block	3 to 6%
Scoria block		Bituminous macadam	6 to 8%
Hillside brick	10 to 12%	Bituminous concrete	
Medina sandstone block	15 to 20%	Cement-concrete	6 to 8%
Granite block	12 to 15%		

Any establishment of maximum grades should be affected by proper consideration of the climatic conditions and character of maintenance likely to prevail after construction in order that objectionable features, such as excessive slipperiness, may be avoided. See (16a).

Minimum Grades. Except on fills where the roadway is so raised above the adjacent ground, or where the latter is so sandy and porous that longitudinal drainage of the roadway is unnecessary, a minimum grade must be established to prevent flooding and saturation of the road-bed by storm water. On city streets where the gutters are smoothly paved, this minimum may be as low as 0.25% but ordinarily should not be below 0.5%. As the roughness of the surface over which the water is to flow increases, the minimum should be raised, and in all ordinary road work, 1% is as small as is practically allowable. Attempts have been made by side ditching to obviate the difficulties attending construction on grades below the minimum allowable, but the results are generally unsatisfactory. The side ditches obstruct ingress to and egress from the adjacent property, are difficult to maintain in good condition and occupy valuable space in the right-of-way. In flat country where wide rights-of-way can be readily secured for the roads, low grades, even nearly level, may sometimes be advantageously established and their objectionable features avoided by carrying the shoulder slopes out to such varying distances from the center line of the roadway as will produce shallow ditches of sufficient grade for carrying the water to the natural water courses or other points where it can be disposed of properly, and the excavation so obtained may be used for crowning the subgrade or making the fills desired. For instance, if at the proposed summit of the ditch grades, the line of the ditch is 12 ft from the center of the roadway and 8 in below it, and at the next station, 100 ft the ditch is 18 ft from the center line, the bottom of the ditch would be 14 in below the center grade of the roadway with a shoulder slope of 1 in to the ft, or the longitudinal grade of the ditch would be 0.5% greater than the grade of the roadway. Such ditches need not cause objectionable crossings of them to be demanded by the adjacent properties, and the possibilities for such construction should be considered. For discussion of minimum grades on Chicago streets see (67).

10. Vertical Curves

Changes in Grade should always be as gradual as practicable and grade tangents should always be connected by easy vertical curves. Breaks in grade lines should, wherever practicable, be always made on streets at intersections and on roads at intersections or turns or other points naturally accounting for the break. It being desirable to have the cross-section of the finished roadway, including the gutters or ditches, uniform and the

ter or ditch grades parallel to the grades of the roadway itself, changes the latter grades will be imitated or followed in the grades of the waterways along the highway. Abrupt changes in the grades of waterways are desirable because of the difficulties that occur against easy and economical maintenance. The abrupt flattening of the grade of a waterway almost invariably causes deposits to be made by storm water carrying silt or other suspended matter, and the consequent obstruction of the waterway. The abrupt steepening of the grade of a waterway creates a tendency for the water to scour the bottom of the waterway at the point of change. To provide protection against both these tendencies may require expensive first construction or excessive maintenance. Changes in the grade of waterways should therefore be made as gradual as practicable, and where possible it is advisable to plan these changes in grade so that they will occur at the points where the drainage is caught by inlets or turned off the roadway to the natural water courses.

Railroad Grades vs Humping. It has too often been the practice, in establishing the grade lines of streets and especially of roads, to lay down long tangents that, with the grading on vertical curves between them, would produce enough excavation for it to be done at a reasonable figure per cubic yard and sufficient in quantity to make the fills properly, and at the same time would keep the total quantity down to what seemed to be a reasonable minimum per mile or unit of length. In such cases, much objection from adjacent property owners usually results from the apparent ignoring in such grades of considerations, minor perhaps from the viewpoint of the highway authorities but of great importance from the viewpoint of the property owner. The change of the grade of a private entrance, if only a few inches in amount, necessitated by the railroad grade or long tangent, may mean its resurfacing at no small inconvenience and cost, whereas greater flexibility in establishing the grade might have avoided the conflict of interests. Again, it has often been the practice in crossing a stream in a bottom to put the grade of the roadway over the stream at a safe elevation above floods, making due allowance for the crown of the roadway, the thickness of the road crust and the depth of the beams of the structure carrying the road over the stream, so that the effective height of the opening carrying the floods is large enough, and then to run level or rising grades from the ends of the bridge each way to the higher ground on either side of the valley. Exactly the same thing is too often done in the cases of culverts or pipes. Vertical curves in grades are seldom objectionable to traffic unless too abrupt, and in the above referred to cases, savings could frequently have been effected in first cost by dropping the grade either side of the bridge, culvert or pipe at least to the height of the effective stream opening so that the fill across the bottom would only have been the minimum necessary to have the sides of the roadway safely above flood mark and then rising by proper vertical curves in the grade to pass over the structure or to the grades on the higher lands.

Vertical Curves between grade tangents, especially where located at the top of a hill, should be of large enough radius to provide for a proper line of sight between vehicles approaching each other from opposite sides of the hill, particularly where high speed motor traffic is prevalent. This radius should not be less than 50 ft in most cases.

WIDTHS

11. Æsthetics and Local Environments as Affecting Width

Considerations Other Than Those of Traffic may affect the decisions as to the width to be provided. This is particularly evident in cases of park drives and boulevards. It is also important for consideration where planting spaces for trees and sidewalks are to be established, or seem likely to be desired in the future. An appreciation of the desirability for various reasons of trees along many city streets, as well as along country roads, is growing in the United States, and the examples set by France in this respect are being emulated. See (58a), (58g) and (71). Proper regard should be had in the preliminary consideration for the provision of sufficient width in the highway so as to satisfy future demands on the space set aside for public purposes, such as tree planting, bridle paths, footways, pipe and wire lines and railway tracks. It is seldom that provision is made for too wide a highway. Occasionally a case is found where unnecessary width seems to exist, and a narrowing of the highway width has taken place in order to obviate the difficulties of proper maintenance of the unused portion, and in order to return to profitable cultivation the idle ground. These cases, however, are rare in this country and the instances of too narrow highways greatly outnumber those of the too wide.

Æsthetic Considerations frequently make it desirable to increase the width determined for the roadway when this figure has been properly made from economical standpoints. A long straight roadway of a definite width will appear to be much narrower than a short one of the same width. Sidewalks where the building line and the lot line coincide may appear inadequate and narrow to a far greater extent than where the building line is set back from the lot line some distance. See (43a). Lack of restrictions as to height of buildings may properly demand extra width for a street. Additional width for the beautification of park drives and boulevards will depend upon the peculiar conditions of the case. The topography of the country traversed may have a decisive influence on the determination of the width, two roadways with a reservation between them frequently being provided across steeply sloping ground, the roadways thus being at different elevations in order to avoid offending in the matter of appearances at least by having either roadway depart too greatly from the natural surface of the ground, and also perhaps for decreasing dangers to traffic. See (29d) and (58g).

Local Environments or possible changes in these should be carefully considered in fixing the width of highways and of their roadways. For instance a former retail district, which has changed to a wholesale district, can perhaps afford some sacrifice of the sidewalk space originally provided and the extra width thus obtained be put to advantage in the roadway. A large commercial truck backed against the curb will occupy about 13½ ft of the width of the roadway, and as these trucks are usually when loaded about 8 ft over all in width, to provide for the easy passage of two lines of traffic between trucks backed up against each curb would necessitate a total width of roadway of at least 45 ft with proper regard for clearances. See (43a). In retail districts, where the pedestrian traffic is of greater importance, every effort should be made to accommodate it, even to the extent of narrowing the width of the roadway to the minimum practicable and at the sacrifice even of making the roadway so narrow that it will become a ONE

AY street permitting the passage of vehicles only in one direction. See (58d). In residential districts, an ample width of roadway is often provided at 25 ft. See (58e). The importance in width determinations of considering the character of the district thru which the street runs and its tendencies to change from one class to another is evident. See (58g). Street widths are generally stated as the distance between property lines. Building lines sometimes coincide with the property lines and sometimes, more especially in residential sections, are considerably behind them. In the foregoing figures regarding widths, no consideration is had of the occupancy of the roadway by street car tracks, and in establishing widths, the existence or probabilities of the entrance of street railways into the roadway in question should be carefully considered.

Subsurface Structures, such as pipe galleries within a street may seriously affect the width of the roadway. It is desirable to keep such structures under the sidewalks as far as practicable in order that the more serious inconvenience to traffic caused by the tearing up of the roadway surface so as to reach the substructures may be avoided. In some instances, the presence or possibilities of vaults connecting with adjoining buildings and constructed under sidewalks by special franchise from the municipality may limit the location of the curb and the reduction of the sidewalk space. See (27).

Standing Places for Teams frequently have to be provided in small towns, and this has often been done by paving a fairly ample roadway thru the center of the street and then leaving unpaved the shoulders or flanks between the edges of the road crusts and the curbs or gutters. Where this has occurred in front of stores or business houses and animal-drawn vehicles have been left standing for greater or less periods, the results have been obnoxious from many points of view. The unpaved areas have been worn down, often dangerously, by the stamping of the animals' feet, so that they require an excessive expense for their maintenance in good condition. Keeping these unpaved areas clean and sanitary under these conditions has been difficult and expensive and the general condition of the street has usually been unsatisfactory. If therefore the hitching of horse-drawn vehicles is to be anticipated along a street, proper consideration of the fact must be had and provision made for such width and character of pavement as will enable the objectionable features above mentioned to be avoided.

The Character of the Shoulders to be provided along the flanks of the roadway will affect the decision as to the width of the road crust. Where the road crust itself is to be narrow, sufficient roadway for accommodating the traffic will have to be provided by the construction of proper shoulders along the flanks so that safety will be had for passing vehicles. Even where the road crust is to be of ordinarily sufficient width to accommodate passing traffic, it may be desirable to provide further accommodations for a portion of the traffic, such as horse-drawn vehicles, especially where the road crust itself is used mainly by motor vehicles and is, or becomes, smooth and perhaps slippery on its surface. A considerable demand seems to be accumulating for the provision of suitable side paths or shoulders for horse travel along bituminous surfaces so frequently found provided for motor traffic.

The Report of the Committee on "Shoulders for Concrete Roads," 1914 Nat. Conf. Concrete Road Building (59), which should be considered in all cases as far as it may be applicable in connection with the other preliminary investigations affecting the determination of matters of width, contained the following:

"With the almost universal tendency in concrete road construction to keep the width of concrete as low as practicable in order to reduce the first cost per mile of the improvement of a road has come, in many cases at least, a neglect of proper consideration of the matter of shoulders. Often the neglect referred to has unquestionably resulted in extravagance and waste in the long run even if it has secured economy in first cost.

"While authenticated records covering reasonable periods and concerning relative expense for the proper maintenance of road crusts and of shoulders respectively are not readily available, certain instances of such records together with the individual experiences related by many authorities tend to show that the shoulder maintenance cost may be no inconsiderable part of the total maintenance cost of a modern road, and that it may often be real economy to build the road crust wider in order to reduce its annual expense for maintaining the shoulders and thus the total maintenance cost per square yard. * * * The actual width of the concrete roadway to be built must be determined by the traffic conditions to be expected on the road and if these are sufficiently heavy to warrant so doing, it will probably be economical often to make the concrete itself wide enough to permit the passing of two lines of traffic wholly on its surface and without any necessity for either of the passing vehicles to travel off the concrete onto the shoulder. On the other hand, traffic and other conditions may be such as to permit the greatest economy to be had by making the concrete only wide enough for one line of traffic and allow the occasional passing vehicle to travel on the shoulder for the moment."

The Composition of the Shoulders or the character of material forming the shoulders may affect the decision as to the width of road crust to be determined upon. If for instance, a good gravel is readily available for the construction of the shoulders, the minimum width of road crust may be built and reliance placed on the shoulders themselves for sustaining a considerable portion of the strains caused by the passage of relatively infrequent traffic over them. On the other hand, if the material available for the shoulders is clayey in character, even the occasional turning out of a vehicle on to the shoulders may result in serious damage to the road crust itself from the tracking of mud from the shoulders on to the surface of the road crust, or from the cutting of ruts which will hold water just along the edges of the crust. It has been observed that in many cases of bituminous surface treatments, the road crusts themselves have been seriously damaged, where too narrow to prevent the more or less frequent passage of vehicles out on to the shoulders, by the tracking of the mud from the shoulders on to the bituminous surface and the subsequent emulsification of the bituminous material in wet weather. With the shoulders composed of fairly clean sand, this emulsification is not nearly as readily had, and a greater amount of traffic under such conditions seems necessary to produce the same result. The minimum width to be established for the road crust will therefore depend to some extent upon the character or composition of the adjacent shoulder.

The Shoulder Maintenance to be Expected may affect the width of the road crust to be determined. If shoulders are expected to carry a considerable portion of the traffic, their proper maintenance must be assured in order to prevent excessive damage and maintenance expense of the road crust, and if such maintenance cannot for any reason be expected from careful consideration of all conditions affecting it, then a greater width for the road crust itself must be determined upon in order to secure satisfactory results as well as economy in the long run.

12. Traffic Considerations as Affecting Width

The Width of Roadway beyond a minimum necessary for safely and economically sustaining one line of traffic will depend on the frequency of passing vehicles, and to a certain extent at least on the character of the vehicles and their rate of speed. The Special Com. on "Materials for Road Construction," Am. Soc. C. E. (15a), has stated as follows:

"Where motor traffic forms a considerable proportion of the total traffic likely to use the highway, the unit width of traffic lines should be considered as 9 or 10 ft instead of 7 or 8 ft as heretofore, because of the greater clearance required for the safe passing of the units of such traffic. In view of the recent constant and rapid increase

of traffic on highways, it will be in the interest of economy for designs on highways to be made with proper consideration of further increases." See (58e) and (71).

Single Track Roadways are advocated in certain sections by some authorities in order to permit of a reduction in first cost per mile and a consequent wider distribution of the funds available, thus allowing perhaps a quicker demonstration and effect of the efforts for general road improvement, but it is only rarely upon investigation that such roadways will be found economical in the long run and that justification for thus distributing borrowed funds will be afforded. The greater concentration of traffic on such roadways necessitates stronger construction of the foundation and of the narrower crust to an extent frequently offsetting the saving had from the reduction of width, and the cost of maintenance of the shoulders in these cases is unavoidably increased. The minimum width of single track roadways is variously placed at 8, 9 or 10 ft, the latter figure probably being the better with proper consideration for fast motor traffic.

Two Lines of Traffic require not less than 12 ft in width of roadway for passing, and two vehicles, even tho slow moving, generally occupy a greater width than this in clearing each other. Within limits, the greater the speed of passing, the more width is demanded, so that 14 ft is about the minimum which should be provided for a double track roadway for slow traffic and 18 ft for fast. Some authorities insist that no width of roadway between 10 and 18 ft is justifiable, but expediency may demand in many cases the adoption of the intermediate widths for some localities. See (43a).

Too Narrow Roadways encourage the concentration of traffic and the development of ruts or at least excessive wear on strips parallel to the center line of the road crust, especially where the shoulders are properly provided with a sufficient slope, greater than the crown of the road crust, and usually about 1 in to the ft. This concentration of traffic increases the difficulties and expense for maintenance and a narrow road crust frequently increases the dangers to traffic in slippery weather when a skid to the soft shoulder material nearby may result disastrously. The standard widths in feet adopted by some of the leading states for road crusts have been as follows with an increase of width in many places because of special conditions: Arizona, 18; Illinois, 10; Maryland, 12, 14 and 16; Massachusetts, 15; New York, 16; New Jersey, 16; Pennsylvania, 16; Wisconsin, 9; For a detailed discussion regarding the Illinois standards see (29c), and for the Massachusetts standards, see (54a). See Sect. 6.

A Determination of the Proper Width of the roadway by calculating thru a formula from a traffic census or estimate has been proposed.

Green (38) has stated that: "One of the points which it is believed has been neglected in the past is the relation of traffic to roadway width, especially where traffic is dense. It seems to the writer that it is possible to establish a logical, if empirical, formula which would be of considerable help at times in the solution of this vexatious problem," and he goes on to propose a formula for a curve in which

$$Y = \frac{X}{6} + 16$$

where Y represents the roadway width in feet and X the number of vehicles." See (39).

Street Widths may be affected by considerations other than those of vehicular traffic alone. In some cities, it is the custom to fix arbitrarily a portion of the total right-of-way for the roadway and to leave the balance for the sidewalks, as well as to make the width of the total right-of-way a certain figure dependent upon the local development of the adjacent property, either existing or seeming to be likely. Baltimore, for instance, allows ⅗ of the total width of right-of-way for the roadway. Such a method of

determining the width of the roadway is not always advisable, as it frequently results in an unnecessary expense for construction and for maintenance on residential streets, to say nothing of the injury to the appearances in such cases, and it would be better to fix the width of the roadway to suit the traffic conditions, occupying as much of the balance of the right-of-way as might be advisable with the paved footways, and leaving the remainder of the right-of-way for planting spaces. These planting spaces could later be taken into the footways or into the roadway as conditions at that time justified. See (58e). For residential streets without street car tracks, 25 ft of width between curbs will permit of the ready passage of a single line of traffic between vehicles standing at each curb. With a single pair of street car rails in the center of the roadway, 30 ft between curbs is as little as will conveniently accommodate the passing traffic, or provide space for an occasional wagon being backed up to the curb for the delivery of coal and like goods. With double car tracks in the center, the roadway should be not less than 40 ft between curbs. Increases over these figures will result from special arrangements of car tracks, planting spaces, bridle paths, cab stands and the like, or because of the needs of more lines of traffic. Space for sidewalks or footways on the flanks of the roadways should preferably be provided to an amount equal on each side to not less than one-third the width of the roadway, tho the whole of the space may not need paving and part of it may be devoted to plantations. This space, however, should be reserved and not be allowed to be obstructed by steps to buildings or other encumbrances of a permanent character. See Sect. 7 and (43a).

Changes in Traffic Conditions (see Art. 16) may materially affect the desirable width of the roadway, even tho changes in the width of the highway itself are impracticable. Thru traffic imposed on a residential street would, for instance, with the more or less frequent passing of vehicles moving at fair speeds, render the 25 ft roadway referred to insufficient in width. The change of a wholesale to a retail district may cause objections to be raised by shoppers against an unnecessarily wide roadway to be crossed. Again an unnecessarily wide paved roadway, especially if unshaded by trees, will needlessly increase the amount of heat radiated in summer to residences along the street. See (29e), (47) and (58g). The possibilities for a change in the traffic conditions of a street must therefore be carefully considered in connection with the determination of its width or that of its roadway. See Art. 15 and (14a).

TRAFFIC INVESTIGATIONS

13. General Considerations Relative to Traffic

Highways are Built for Use by Traffic. An engineer should not design a highway without considering the character and amount of traffic the highway would be expected to serve efficiently. See (19a).

The recommendation of the Special Com. on "Materials for Road Construction," Am. Soc. C. E., in its 1913 report in this connection, was as follows: "Your Committee desires to emphasize the fact that experience has demonstrated the value of traffic censuses taken both preliminary and subsequent to the construction of a highway. The traffic census should be considered one of the most important variable factors in the solution of that important problem, the selection of that type of road or pavement best suited to local conditions considered from both the standpoints of economy and efficiency. In connection with the census returns on any road should be considered the traffic on cross and parallel highways, and the effect of improvement of these highways on the traffic of the highways under consideration. It should not be taken for

granted that the bald return of a traffic census should be the sole basis of the selection of the type of construction adopted. The form for a traffic census proposed by your Committee has proved satisfactory and its future use is recommended." This form has also been endorsed by the 1916 Convention of the Am. Road Builders' Assn.

Traffic Affects the location, lines, tangents and curves of a highway, its grade, width and foundations. It affects the decision as to the kind of surfacing to be selected, its thickness and the considerations as to smoothness, noiselessness and dustiness. See (40). Traffic also affects the character and cost of maintenance. See (7).

The Importance of Properly Considering Traffic on a highway may be evident but it is necessary to take into account first some of the complexities of traffic conditions and some propositions that have been made concerning the desirable simplification. The traffic over a highway is usually made up of various units, no two of which may be exactly alike in their effect. For instance, the effect on the roadway of a loaded two-wheeled cart drawn by a single animal is quite different from that of a pleasure vehicle drawn by a rapidly trotting horse, and the effect of a swiftly moving motor car is very different from that of either of these. It can be readily seen that the simple summation of the count of vehicles passing a given point on a highway will not necessarily give a clear idea of the strains to which the roadway is subjected at that point. Again, if it be assumed that in any particular case the bulk of the traffic over a road is made up of horse-drawn commercial vehicles, and that the effects of motors on the road are negligible, a simple count of the traffic will not furnish sufficient information, because of the variations in the speed or distribution of this traffic. For instance, on some of the roads adjacent to marketing sections, the traffic is so extremely light as to be almost negligible except for certain hours in the day, when the teams carrying produce come in or go out in long lines, the slow moving units following closely one after the other for a few hours. The effect of this traffic is quite different from the same amount of faster traffic uniformly distributed over the daylight hours.

The Weight or Tonnage Basis alone is not a proper one for comparisons of traffic nor does it always bear a direct relation to the effect of traffic on the roadway. Slow moving vehicles produce quite different effects on the road surface and demand different consideration than in the case of swiftly moving vehicles such as touring cars. On the other hand, it is important to consider the range of the weights and sizes of the units of traffic in determining some of the questions connected with highway design. See (11).

The Sizes of the Wheels of vehicles using the highway may be of considerable importance in the consideration. The tendency of some of the bituminous pavements to shift into corrugations or waves under different classes of traffic is partly due to the pushing tendency of the relatively small wheels either in the direction of the movement of the vehicle or, in the case of driving wheels, in the opposite direction, especially when this pressure may be more or less intermittently applied and thus reaches a periodic maximum from the more or less rhythmic vibration of the engine and of the load transmitted or accented thru the springs.

The Character and Width of the Tires of the traffic influence the effect of the traffic on the highway. Steel tires on wheels tend to produce a destructive effect by shock and abrasion on the surfacing material, and if narrow may concentrate the load to a considerable extent. Elastic tires generally distribute the load over a greater area and lack the tendency of steel tires to pound or abrade the surfacing material. On the other hand, they

may possess a decidedly injurious ability to sweep the road surface of it fine material and thus to permit the loosening of the coarser particles c the polishing of the entire surface so as to render it slippery.

Comparisons or Estimates of Traffic should include proper consideratio of the various factors above mentioned, and proper comparisons or estimate of traffic effects attempted by merely counting the vehicles of each kin passing over a road in a stated period are impossible. Further they ar lengthy and unwieldy and do not permit of ready comprehension of even th relative amount of traffic. The reduction of such traffic censuses in suc a way as will permit comparisons to be readily made and a relation to b established in any case between the reduced figures and the effects c traffic on the road is not only desirable but necessary. The method c reduction in any case need not be exact, but it should be, for the greates benefit, one which will have general support by highway authorities. Sucl a method has not yet been adopted. Exact accuracy of method not bein necessary for the present at least, an empirical agreement rationally mad and of general adoption would be a great step in advance. Ultimately further steps might be taken toward exactness.

A Reduction of Highway Censuses may be made in two ways. A calcu lation of tonnages, modified by importance factors and related to costs as measures in different areas, of the combined efficiency of the roads anc the vehicle has been suggested, or severity factors may be assigned to th vehicle and endurance factors to the different kinds of roads, and th efficiencies then compared on importance-tonnage in relation to the averag severity-endurance factor per mile. See (26j).

The British Unit of Traffic, adopted by the Road Board, is the British ton, and th calculations are based on the weight of the traffic in tons per yard of width per yea or per mile. The weight for the unit of each class of traffic appears to have beer obtained by averaging the actual weights of a considerable number of each unit. Th British engineers, however, in making their report (66) to the 3rd Int. Road Congress stated: "That the relative damage or wear due to different kinds of vehicles depend so largely upon other factors than weight that the details found by applying th weight factors to the results of the enumeration do not indicate the relative detaile effect in each case. If the weight is to be a measure of severity, we want separat classes for (1) traction engines; (2) heavy motor cars; (3) ordinary motor cars; (4) horse vehicles with tires of proper width; (5) horse vehicles with narrow tires; (6) bicycles. Generally the greater the traffic on a country road, the better is its distribution, and the amount of wear is therefore in simple proportion to the amount of traffic. Under some conditions, over 80% of the vehicles passing along an 18 ft road may use the middle 8 ft of the road, or on a 26 ft road, over 70% may use the middle 8 ft."

The British Road Board Unit Weights are as follows:

Classification of Vehicles	Assumed Average Weight in Tons
Ordinary cycles	0.09
Motor cycles	0.18
Motor cars (including motor cabs and any other motor vehicles not specified)	1.6
Motor vans (covered)	2.5
Motor omnibuses	6.0
Motor lorries (rubber tires)	6.0
Trailers to rubber-tired lorries	5.0
Motor lorries (steel tires)	10.0
Trailers to steel-tired lorries	5.0
Light tractors	5.0
Trailers to light tractors	5.0
Traction engines	12.0

Classification of Vehicles	Assumed Average Weight in Tons
Trailers to traction engines	8.0
Light vehicles (one horse)	0.4
Light vehicles (two or more horses)	0.6
Heavy vehicles (one horse)	1.25
Heavy vehicles (two or more horses)	2.5
Omnibuses (two or more horses)	3.0
Tramcars (electric, steam or horse, as the case may be)	....
Horses (led or ridden)	0.5
Cattle	0.3
Sheep and pigs	0.1
Hand-carts and barrows	....
Horses drawing vehicles (to be calculated from number of vehicles)	0.5

The French Unit of Traffic is the Collar, being a draft animal harnessed to a wagon. For special studies, another unit per ton (1000 kg) is also used, but the tonnage is calculated from the collar basis, and ordinarily the collar unit is the one in use. A very complete report in the matter was presented to the 2nd Int. Road Cong. in 1910 (55). In this report, recognition is given to the general principles heretofore expressed and illustrates their consideration and application under French conditions. Briefly, it is stated that it is not sufficient in order to know the importance of the traffic at a given point to know the total number of collars passing there. All traffic is not of the same commercial value nor has it the same influence as to the wear of the road and hence as to the expense of maintenance. A large truck or farm wagon heavily loaded has a very different action on the road crust from that of an empty carriage. Cavalry horses, animals going to pasture or to market can not in their effect be likened to horses which draw vehicles. In the earlier censuses, because of the recognition of these facts, categories for the enumeration were very numerous, but this complex classification was an embarrassment. In the census of 1882, and those that have followed, but five classifications have been preserved, these five "comprehending the different vehicles whose action on the roadways seems to be practically equal and measurable by the number of collars noted." The first class embraces trucks and farm wagons loaded. The second class embraces public vehicles designed for transporting passengers and their baggage. The third class includes light vehicles, such as empty farm wagons and private vehicles. The fourth class comprises animals, such as horses, mounted or not, large cattle, mules, etc. The fifth class comprises small beasts, such as sheep, goats, and pigs. In 1903, for the first time, attention was paid to the automobile and these vehicles were separately divided into five classes. In the first, were included automobiles with metallic tires, "which in general are heavily loaded, have a slow movement and produce the effect of wearing away the road surface." The next three categories included respectively, automobiles with elastic tires, motors licensed, under the French system, to make a speed of more than 30 km per hr; automobiles whose speed was less than 30 km per hr; and bicycles or velocipedes propelled by the feet of the rider. The fifth class comprised motor cycles whether having two, three or four wheels. The report states that "in order to draw from the censuses conclusions relative to the charge," which "the maintenance of the road imposed on the public treasury," it is necessary further "to attribute to each element of the traffic an importance which belongs to it from the viewpoint of the destructive effect exercised on the road crust." To this end, the total numbers stated by the count are modified by coefficients of reduction varying between the different classes, and the total of the quantities thus modified gives the figure of circulation which is characteristic of the frequentation of the roads from the viewpoint of maintenance service, and the practical measure of the strains on the roadways. In the census before 1882, animals not harnessed and small beasts were neglected.

All animals harnessed to a vehicle carrying a load counted as a collar, and vehicles circulating empty as ¼ collar each, but this was considered unsatisfactory, and in 1882, and the succeeding censuses in 1888, 1894 and 1903, a collar was taken as an animal harnessed to a loaded vehicle regardless of the size of the animal itself. It appeared preferable to maintain the value of unity for such a collar regardless of any disadvantage particularly accruing to sections where small animals were used

because in those sections, which are generally in mountainous or arid regions, the roadways are exposed to other causes of severe wear. Collars harnessed to public vehicles for passengers were not reduced. The weights drawn by a collar in that category are only in truth about three-fifths of that drawn by a collar attached to a vehicle with farm products or merchandise, but the speed is that of a trot and an equal load is much more destructive than at a walk. For empty and private vehicles, altho the mean weight of these vehicles is three times less than that of the loaded vehicle, a coefficient of reduction applied to them it seems should be more than one-third in order to take account of the action of the feet of the horses, and also of their speed which, for a large number, is that of a trot. For this classification, the coefficient ½ is adopted. All horses not harnessed but mounted by a rider, or loaded on its back, are considered as having a weight equal to that of a harnessed animal. Their action, on the other hand, is thought less destructive because it does not exercise the horizontal effort to the same extent. It is therefore considered rational to count each for a little less than harnessed horses, which enter for ¼ in the weight of a collar, and it is thought proper to attribute to an unharnessed horse, the coefficient 1/5. This coefficient is applied equally to cattle, which, tho their weights are not always equal to horses, are considered as having the same wearing effect on the roadway. As to the head of small beasts, their weights vary from the mean, the latter being 1/7 and ⅛ that of horses, but their action on the roadway is considered more severe because of the conformation of their feet. It is considered that six of these animals wear the road as much as an unharnessed horse and the coefficient of 1/30 is therefore applied to each of them. A summary of French coefficients is as follows:

First and second categories, wagons loaded with farm products or merchandise and public vehicles for passengers, each equals 1.

Third category, empty vehicles and private vehicles, each equals ½.

Fourth category, animals not harnessed, each equals 1/5.

Fifth category, small beasts, each equals 1/30.

A modification of the above employed since 1888, applies to the manner of counting the number of harnessed cattle. When the censuses for 1882 were taken, it was believed necessary to reduce to one collar a span of cattle because of the light loads drawn by these animals in certain regions where they are commonly employed, but the rule was abandoned and a pair of cattle counted for two collars when they were harnessed to heavy loads, such as minerals and coal. In order to avoid arbitrary decisions on the part of the observers because of this variation, it was decided that for the census of 1888 and those following, the real number of cattle employed as draft animals should be counted each as one collar. Consideration is had by the French of the influence of tramways or street railways on the wear of the contiguous roadways. As a result, the Nat. Road Comm. valued at 8 1/5 collars the mean daily circulation of the tramways and street railways for the census of 1884, but it expressly reserved the right to change this figure as might be decided necessary later.

AUTOMOBILES in the census before 1904 had been counted as a number of collars equal to the proportion of the total weight of these vehicles to the mean weight of a one-horse cart loaded, including the weight of the horse, but in view of the increasing importance of motor traffic, the Nat. Road Comm. prescribed, by a ministerial circular of April 27, 1904, as follows: "First, to determine the number of collars equivalent to automobiles with metallic tires, divide the mean weight expressed in tons of 1000 kg by 1.25; second, automobiles with elastic tires shall be counted in collars as follows:

Motor cycles	0.3
Vehicles licensed to make a speed of over 30 km per hr	3.0
Vehicles licensed for only a speed of less than 30 km per hr	1.0
Motor cycles, whether of 2, 3 or 4 wheels, with elastic tires, and with the rider in the saddle	0.05

By means of these coefficients of reduction, it is thus possible to reduce the mechanically propelled traffic to figures which can be added to the animal traffic also reduced, and thru a summation, to represent thru the collar unit the measure of use of the roadways.

TONNAGE was the second object of the censuses, the first being the expression of the circulation in collars achieved as above described. The tonnage was valued according to the weights transported each day or, more generally, during the entire year.

Mean weights were established by weighing a large enough number of units of each classification, and applied to a collar in each category. In the establishment of the mean weights, consideration was also had of the portion of the total weight made up by the useful load, and this was obtained by deducting from the total weight the dead weight of the vehicle. In the censuses before that of 1882, the weight of travellers was included in the useful tonnage, but since 1882, the useful tonnage has not included the weight of passengers nor, on the same principle, of passenger motors with elastic tires and velocipedes carrying only passengers. Again, as regards animals not harnessed moving over the roads and transporting themselves from one place to another, their tonnage has, since 1888, been included in the calculation of useful tonnage, while animals mounted or loaded, which represented a means and not a matter of transport, were not so included.

Italian Traffic Censuses have been taken since 1882 by different provinces and a report presented to the 2nd Int. Road Cong. (74) describes these in more or less detail. The first census of the departmental routes in the Province of Pisa in 1893 followed the French censuses in many respects. The unit was the barracio, cart loaded, drawn by one or two horses. An empty cart was valued at 0.5 and a wagon loaded, drawn by three horses, at 1.25, and the same empty at 0.75. The victoria counted as 0.5. Draft animals and large beasts were counted as 0.2 and small beasts at 0.03. The tonnage also was approximated as closely as possible. The results obtained were only of local value.

The Province of Bologna took a traffic census in 1900. Their unit was a draft animal attached to a cart with a load, and the same was counted for 0.5 if the wagon was empty. Large beasts were valued at 0.2 but no account was taken of small animals.

The Province of Modena took a census during the years 1901 to 1904, and the unit adopted there was the collar or draft animal attached to a loaded wagon, or to an omnibus or to a public carriage, and the value of ½ was given the same animal harnessed to an empty wagon or to a light cart. Large beasts counted at $1/_5$ and small beasts at $1/_{30}$. In order to translate the traffic figures so obtained into tonnage figures, it was estimated that each draft animal transported at least 2½ times his own weight and that this weight was 400 kg for flat country and 350 kg for mountainous country.

The Province of Padova took a census on the simple basis of dividing the vehicles into two categories, light, that is to say, vehicles empty or passenger vehicles, and heavy.

The Province of Milan has taken what is stated to be probably the most complete of the Italian censuses. Their first was in 1904 and this was succeeded in 1907 and followed up in 1908, 1909 and 1910. The values given to the different units of traffic in this instance were as follows:

1 motor vehicle	= 2 collars
1 animal attached to a loaded vehicle	= 1 collar
1 animal attached to an empty vehicle	= $1/_2$ collar
1 large animal not harnessed	= $1/_5$ collar
1 small animal	= $1/_{30}$ collar
1 bicycle	= $1/_{20}$ collar
1 push cart loaded	= $1/_5$ collar
1 push cart empty	= $1/_{10}$ collar

Trucks, including motor trucks, were counted according to their weights in a separate column. In the case of many animals attached to one vehicle, the first was counted at ½ and the others at $1/_5$. Trucks were translated into collars by dividing their total weights by the average weight of one collar.

In the Netherlands, traffic censuses were taken in 1908 and a report made in the matter to the 3rd Int. Road Cong., 1913, by Wentholt (75). A coefficient of traffic was used, which it is stated was "obtained by increasing the number of vehicles with light loads to twice the number of mechanically propelled vehicles, and twice the number of vehicles with heavy loads, and by adding to the figure thus obtained one-fourth of the number of hand carts and carts drawn by horses, etc."

The Illinois State Highway Authorities have taken traffic censuses in 1906, 1908, 1910, 1911 and 1912. The basis in the earlier censuses appears to have been the vehicle itself, loaded and unloaded vehicles being recorded separately. The instructions

of the Ill. Highway Comm. regarding the taking of the census, on this point, include the following: "All passenger vehicles, as carriages and buggies, are to be classed as unloaded. All wagons carrying any load will be classed as loaded; otherwise as unloaded. A carriage of any kind should always be recorded as unloaded, whether all seats are occupied or not." Apparently no coefficients of reduction of any kind were provided for reducing the counts so obtained to a single figure indicative of the amount of traffic. Interesting discussion and detailed figures of the Illinois census may be found in the reports of the Commission (45).

The Maryland Highway Authorities began to take traffic censuses in 1904 and have continued more or less irregularly. Except for special articles on this matter (2) (26a), (26b), no publication of the Maryland results have been made by the Maryland authorities. From the special articles referred to, it appears that the earlier Maryland censuses were based on the following classifications: (1) ridden horses and one-horse vehicles; (2) two- or more horse vehicles; (3) cycles; (4) motors. This classification was changed in 1906 to provide for the following: (1) ridden horses and one-horse vehicles; (2) two-horse vehicles; (3) more than two-horse vehicles; (4) motors. In the censuses beginning with 1910 and subsequently, the classification adopted followed that recommended by the Special Com. on "Materials for Road Construction" of the Am. Soc. C. E., and is as follows: (1) ridden horses and one-horse vehicles; (2) two-horse vehicles; (3) three-horse vehicles; (4) four-horse vehicles; (5) five- or more horse vehicles; (6) motor cycles, including bicycles; (7) motor runabouts; (8) four- or five-seat touring cars; (9) six- or seven-seat touring cars; (10) motor trucks or drays. The values assigned to each of the foregoing classifications for the purpose of reducing the rather elaborate tabulation, so that comparisons could be readily made, were as follows:

1. Ridden horse and one-horse vehicle	2
2. Two-horse vehicles	4
3. Three-horse vehicles	6
4. Four-horse vehicles	8
5. More than four-horse vehicles	12
6. Motor cycles	2
7. Motor runabouts	10
8. Four- or five-seat touring cars	20
9. Six- or seven-seat touring cars	40
10. Motor trucks or drays	20

For discussion of these coefficients of reduction and for further details in connection with the Maryland censuses, reference may be had to publications, other than those already noted, as follows: (26b) and (26j).

The Mass. State Highway Comm. took traffic censuses in 1909 and 1912. Their classification was as follows: Horse drawn vehicles, single horse light, single horse heavy, two or more horses light, two or more horses heavy; and automobiles, runabouts, touring cars and wagons, trucks and omnibuses. The Massachusetts authorities appeared to have followed the British method of relying on weights for a reduction of the census figures and in the report of the Mass. Highway Comm. (54d), which may be referred to for detailed discussion of the censuses, they state as follows: "After all, it is not numbers which tell the story, it is weight, and it is not weight alone but the vehicle by which it is transported, whether by horses or by motor. It is not the tractive power alone that makes the difference, but the tires which support the vehicle, whether iron or rubber comes in contact with the road, whether the vehicle is pulled over the road or propels itself, and thus pulls upon the road surface. All of these considerations are probably not so important on many road surfaces as the actual weight imposed upon the road per inch width of tire resting upon the road. * * * After careful study they have adopted in England an assumed weight or coefficient for each kind of vehicle using the roads, in order to make a fair comparison of the traffic upon different roads where the traffic varies, and to more nearly show what the road must support. It is quite similar to the formula in use in France and on the Continent. It is therefore used both for want of a better one and also because it gives a fair basis of comparison." The accuracy of some of the above expressions may be questioned.

The WEIGHTS used by the Mass. Comm. for the different classifications made up by them are as follows:

Motors	
Runabouts	1.43 tons
Touring cars	2.23 tons
Trucks	6.25 tons
Horse-drawn vehicles	
One-horse, light	0.36 tons
One-horse, heavy	1.12 tons
Two or more horses, light	0.54 tons
Two or more horses, heavy	2.46 tons

The N. Y. State Highway Dept. took a traffic census in 1909 and the basis of the census with the reduction figures assignable to each classification were as follows:

Class of Traffic	Relative Weight
Horse-drawn traffic	
Horses with vehicles	1
One-horse vehicle, light	2
One-horse vehicle, heavy	3
Two-horse vehicle, light	3
Two-horse vehicle, heavy	4
Three-horse vehicle, heavy	5
Four-horse vehicle, heavy	6
Motor vehicles	
Motor cycles	1
Two-passenger cars	2
Three-passenger cars	3
Four-passenger cars	4
Five-passenger cars	5
Six-passenger cars	6
Seven-passenger cars	7
Trucks, omnibuses, etc	10
Miscellaneous	
Traction engine	15
Two traction engines	30
Miscellaneous heavy traffic	5 upward

In the compilation of the census figures, a summary was made so as to give separate columns for the horse and for the motor traffic. For further details, see (17) and (32).

The U. S. Office of Public Roads has made some traffic studies, and a particularly interesting résumé of these on the Rockville Pike may be found in (46). James and Reeves, the authors, there refer to the difficulties met with in the attempted establishment of proper traffic units and argue for the adoption of the TON-MILE basis. The weights they give to the various items in the category of vehicles are as follows:

	Tons
Loaded 1-horse wagon	0.88
Unloaded 1-horse wagon	0.28
Loaded 2-horse wagon	1.57
Unloaded 2-horse wagon	0.47
Loaded 4-horse wagon	3.88
Unloaded 4-horse wagon (gears)	0.54
1-horse pleasure vehicle	0.28
2-horse pleasure vehicle	0.47
Rubber-tired horse vehicle	0.28
Saddle horse	0.50
Motorcycle	0.20
Excessively heavy vehicle	3.94
Motor runabout	1.68
Motor touring car	2.00
Loaded motor dray	2.43
Unloaded motor dray	1.23
Draught horses	0.50

Many of the arguments advanced in the article are sound, but apparently insufficient consideration has been given to the relative effects of different speeds, of different kinds of tires, and of the variations in effect of one or both of these on different kinds of surfacings. The ton-mile basis and the conclusions of the authors cannot therefore be generally accepted, for the present, as final. It would seem as tho the ton-mile might be improved on as a basis, altho even then it would not in many cases be perfectly satisfactory. If the relative speed were allowed to enter, this could be included by making the basis the ton-mile per hour and estimating the approximate speed of the passing vehicles. That is, instead of taking the weight of the vehicles and the length of section under observation, the weight of the vehicle multiplied by its speed in miles per hour would give the figure to be used. Owing to the fact that up to a certain limit of speed, the importance of the speed factor is relatively so small compared with the tire factor or the weight factor, it might be possible to simplify the records and calculations somewhat by allowing all speeds below a certain figure to be calculated at unity, and to use for the speed factor a figure other than unity only in cases where the speed was estimated to be over the maximum rate per hour established. A different maximum rate per hour could be set for hard-tired and rubber-tired vehicles if desirable, and the factor for excessive speeds could either be had by obtaining the ratio between the maximum speed established and the actual speed estimated or by empirically stating factors gradually increasing, for the estimated speeds above the maximum. The importance of proper consideration of the matter is again evidenced by the foregoing.

The City of New York has taken some traffic censuses and the classifications and values adopted by the Bureau of Highways, Borough of Brooklyn, are given (68) as follows:

	Weight in Tons	Traffic Value
Rubber-tired vehicles		
Large automobile trucks, loaded	9	5
Large automobile trucks, empty	4	4
Small automobile trucks, loaded	3	3
Small automobile trucks, empty	1½	2
Pleasure automobiles	1¾	1
Carriages	2	2
Steel-tired vehicles		
Loaded trucks	7½	10
Empty trucks	3½	7
Loaded wagons	2½	7
Empty wagons	1½	4
Carriages	1	2
Trolley cars	..	10

To obtain the traffic unit, the following rule was used: "The number of vehicles passing a given point in 8 hr times traffic unit divided by 8 times 60 times the width of the roadway equals density equals traffic units per minute per foot width of roadway. The density of traffic may be divided roughly as follows: Maximum, 1.16 to 1.74; medium, 0.58 to 1.15; minimum, 0.00 to 0.57. This represents in a rough way, in accordance with the above formula, what is known as the maximum, medium and minimum density of traffic in the Borough of Brooklyn."

The Borough of Manhattan has taken some traffic censuses and their classifications of vehicular traffic have been as follows: Horse-drawn iron tired, horse-drawn rubber tired, automobiles, street cars, automobile trucks, with an estimated actual weight for each vehicle counted, these weights being finally totalled.

Conclusions of Various Authorities. Absence of general agreement among highway authorities, except perhaps in the matter of certain general principles concerning the translation of the complex figures from a traffic census into a simple expression of the relative effect of traffic under different conditions, will be evident from the foregoing summary of the conclusions of those authorities who seem to have given most attention to the subject. At the same time, the importance of such general agreement as

might be possible in this connection is also demonstrated. One of the reasons for the lack of agreement is the comparatively short time that attention has been given to the subject outside of France. Another reason is furnished by the quite different conditions prevailing in many instances with these authorities.

The FRENCH conclusions were reached from dealing mainly with water-bound macadam roads, comparatively recently surface treated with tar, and with local environments and traffic conditions appreciably different from those in this country. The same may be said of the BRITISH conclusions with a further remark that the British environments and conditions are perceptibly different from those in France. The ILLINOIS conclusions were drawn from a study of traffic over roads of earth and included but relatively few miles of roadways improved according to modern standards. The MARYLAND conclusions were based on a study of traffic over roads improved with water-bound macadam with surfacings of various kinds, including shell, gravel, water-bound limestone and trap rock macadam, and bituminous macadam or macadam surface treated with various bituminous materials. The MASSACHUSETTS conclusions were admittedly influenced strongly by the conclusions of the British Road Board, but were based on a study of traffic over mainly water-bound macadam roads, some of which had been treated in one way or another with bituminous materials and whose local environments and conditions were quite different from those prevailing in Great Britain or in Maryland. The NEW YORK conclusions were based on a study of traffic over roads recently improved with modern surfacings of various kinds but under local environments and conditions differing considerably from those of Maryland or even Massachusetts. The NEW YORK CITY conclusions were based on a study of traffic over city streets, whose surfaces were in the main pavements of sheet-asphalt or stone block, and whose local environments were decidedly different from those prevailing in any of the other cases. While there may be a difference between the local environments and conditions in the two Boroughs of Brooklyn and Manhattan, it hardly seems sufficient to explain fully the differences in the conclusions of these two boroughs.

As stated editorially by the SURVEYOR (70) a single severity factor cannot be assigned to a particular kind of vehicle or a single endurance factor to a particular kind of crust, the reason being that these factors vary with the different vehicle-crust combinations. "The average severity factor of a rubber-tired delivery van and the average endurance factor of granite setts and water-bound macadam furnish us with no just estimate of the relative effects of the delivery van on granite setts and water-bound macadam respectively. Again, the rates of wear of a particular kind of crust will vary very much indeed according to whether the road is a dead flat, a gentle gradient, or a steep hill, * * * as regards iron-tired motor vehicles, the element of road crust temperature is far more important than gradient for tarred roads." See also (7).

On the other hand, it seems possible to make such divisions of a country even as large, and with as varied conditions, as the United States, so as to include in sections roads with similar crusts, surfaces, alignments, local environments and conditions, and to adopt for each section such a set of relative weights for each classification of the traffic census as would avoid, as far as possible, complications of the tally sheet and the bringing in of uncertainties or the establishing of impracticable efforts on the part of the ordinary observer, and yet at the same time, permit of ready comparisons of traffic in which the actual errors compensate for each other quite sufficiently, and give the highway authorities valuable information from the traffic census itself as to the effect of the traffic on the roadway surface and as to the cost for maintenance and repair.

14. Traffic Censuses

The Method of Taking Traffic Censuses is an important consideration. Continuous recording of the traffic is impracticable for more than a short period at least and yet a fairly accurate idea of the traffic on a highway for a yearly period is necessary. Ordinarily the observers or recorders available for the purpose will not be especially trained for the work, tho, in course of time, they may become more or less experienced in it. Too much reliance should not be placed on the judgment of these individuals, and the requirements of them should be kept well within their capabilities.

The French Methods again have been carefully studied out and in the report pre-

viously referred to of the French traffic census (55) the following description of the methods employed is given: "The roads are divided into a certain number of sections in each one of which it is supposed that the circulation is almost constant thruout the year. At one point in the section chosen is a point of observation, and the observer notes the vehicles and animals of each category which pass before him. These notes are sent to the engineer's office where they are compiled according to certain forms and then transmitted to the Central Department. The choice of posts for observation is the most delicate and most important part of the preparatory work. In fact, there are a very few sections of road where the traffic is constant thruout the year. The local circulation nearly always predominates at most irregular speeds. In the suburbs of cities for instance, it is very active, and then it diminishes more and more, according to the distance away, many of the carriages leaving the main road as they go out. The farm traffic, which goes from the farm to the fields, uses the road only for short distances, whose limits are variable and indeterminate. Results, then, are obtained more or less exact, according to the length of the sections and dependent on the position of the post of observation in each one of them. In order to arrive at the maximum exactness it would be necessary to divide each road into as many sections as there existed branches to it, or other roads crossing it, but one could not do this without exaggerating the expense beyond measure. In order to approach as nearly as possible to this maximum of exactness, the Administration has carefully considered the matter for a long time. Moreover as it is very important that the results of a census be to the utmost comparable with those of preceding censuses, the posts of observation in 1903 have been as little changed from those used in 1894 as local circumstances rendered possible. Exactness of the results depends also largely on the attention and the conscientiousness with which the observations are made. Generally the observers are chosen patrolmen who receive extra pay for their extra work. These observers are supervised by the travelling superintendents whose duties call for their frequently inspecting their roads, and who are in their turn directed and controlled by engineers. Under these conditions, the total results of the censuses are of a nature to inspire a very great confidence.

"The census takes place during the entire year, but consideration of economy prevents the extension of the census to each one of the days of the year, and it suffices to take them at regular intervals and to apply to the entire year the mean of the results thus obtained. This method would not be proper unless the dates of the census taking were well chosen. The circulation at a given point is not constant. If the extremes of commerce and of industry create a permanent movement in each direction, this movement still undergoes variations according to different seasons of the year, and takes exceptional speed on certain dates, the intervals between which are sometimes irregular, such as fair days, holidays, and the more often periodical dates like market days and Sundays. There are also inequalities due to weather conditions. Extremes of weather influence the results more or less, especially if they happen to coincide in a less or greater number with the dates of the census. It is hardly possible, when a count is not made each day to escape the error due to days of exceptional traffic, which are not regularly occurring, and which cannot always be foreseen. As to the periodic influences, generally the most important are eliminated in the main by dividing uniformly the counting days between the four seasons and the seven days of the week. The number of counting days is thus fixed at 28. Each one of the days of the week figures once in each quarter, and there are therefore between two consecutive counts constant intervals of 13 days. The days for counting during the last census taken in 1903 were as follows:

Days of the Week	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter
Saturday	Jan. 3	April 4	July 4	Oct. 3
Friday	Jan. 16	April 17	July 17	Oct. 16
Thursday	Jan. 29	April 30	July 30	Oct. 29
Wednesday	Feb. 11	May 15	Aug. 12	Nov. 11
Tuesday	Feb. 24	May 26	Aug. 25	Nov. 24
Monday	March 9	June 8	Sept. 7	Dec. 7
Sunday	March 22	June 21	Sept. 20	Dec. 20

These days are the same as those which were adopted in 1894, and they were preserved in order to render the results as comparable as possible. As in 1894, a day has been considered as commencing at six o'clock in the morning in the first and fourth quarters and at five o'clock in the second and third quarters, and as finishing uniformly at nine o'clock at night.

"The traffic is small during the night on the greater part of the road except perhaps in the suburbs and at the time of fairs or markets. On the other hand, the night censuses are the most costly and the most difficult to take. In 1888, it was thought that a large number of those counts could be omitted and reliance had at many stations on adding to the early records the mean of one or two observations at night per quarter. It was therefore decided, and it was the same in 1882, that once at least per quarter, the count would be carried thru the entire 24 consecutive hours on each section, and that on the sections where the night counts should be more frequent, they should be of the same number in each one of the four quarters. The administration left to the engineers the responsibility for fixing for each section the dates for the counts which should last thru the 24 consecutive hours, this decision to be made in consideration of the local circumstances such as fairs, markets, etc, to the end that the most exact possible mean of the nocturnal traffic should be had. In 1894, the engineers were left at liberty to fix the dates of the night count without any restrictions to make them the same as the day counts, and the same procedure was followed in 1903, with the recommendation , however, that in any case the total number of night counts should not exceed those made in the previous censuses."

The Illinois Methods as described (45) may be summarized as follows: The work was gradually begun with a few observers in the vicinity of Springfield, and in one or two other sections of the state. These stations were established in Feb., 1906, and from time to time, additional stations were established until a total of 37 was reached. The method of counting and classifying traffic is to record, first, all the the vehicles going in or toward the city or town in which the station is established, and, second, all vehicles going out or away from the town, distinction being made between loaded and unloaded vehicles. The number of horses attached to each vehicle is recorded and the record for each hour kept separately. Instructions on the back of the blanks furnished for recording the traffic require the signature of the observer, the date on which the record is taken, the condition of the road, whether dry and smooth, dry and rutted, freezing and smooth, freezing and rough, wet with mud .... inches in depth, and condition of the weather, as cloudy, rainy or fair. The report further states "each station was established at some house on the road near enough to the city or town in question to include all the traffic going and coming to the country, but far enough out to exclude merely street traffic. The blanks were purposely made as simple as possible with the idea that they could be kept by any bright boy or girl. A count was made at all stations on the same day and were made about four times a month. The days were so selected that if the first count came on Monday, the next count would come some other day of the week; taking, for instance, the first Monday of one week, Tuesday of the next, Wednesday of the next and so on. In winter, the traffic was recorded during the daylight hours, but at all other seasons of the year from 6 A.M. to 7 P.M. The observers in Illinois generally were private parties and were each paid $1 for each day the count was taken. The records of traffic show that counts were taken in this 1906 census from two to five times per month during the year, exclusive of January and December.

In Maryland, the published traffic censuses have been taken more or less irregularly, and have only been taken under the direction of the state highway authorities on the improved sections of the state road system. The observers have in practically all cases been the patrolmen employed in the up-keep of the roads, or employees of the State Roads Comm., especially assigned for the purpose. The effort has been made to secure within the limits imposed by controlling conditions, the records under such circumstances of weather and traffic that fair averages of the use of the roads would be indicated by the figures. Reports included statements as to temperature and weather conditions and any remarks necessary to indicate especial considerations of value.

The Massachusetts Method, as described in detail (54c) may be summarized as follows: Two separate records were taken, the first in the month of Aug., beginning on Sunday, Aug. 23rd, 1909, at 7 A.M. and continuing for 14 hr each day until 9 P.M. on the following Saturday evening. The second census began on Sunday, Oct. 10th

at 7 A.M. and continued for the full week in precisely the same way. For the Aug. records, 237 observers were employed and in Oct., 240 stations were established. In most cases, boys and girls in advanced grades of the public schools were selected for observers, but in some instances, the repair agents of the Commission kept the records. It was recognized that the chief end of such records was, first, to determine the relative importance of different routes of travel, and second, to secure at least a rough approximation of the relative use of such routes by motor vehicles and by horse-drawn vehicles. As untrained observers only were expected to be secured, the data called for was as simple as possible and the tally cards were prepared with care so as to leave little or nothing to the judgment of the observers. On certain of the main roads leading into Boston, the records were taken during the Aug. census for 24 hr each day. In 1912, a similar traffic count was made at 156 stations scattered thruout the state. The time and method of counting were identical at all points, and the census of 1912 was taken on days and for periods similar to those in 1909. Compilations from the records so obtained were prepared in the office of the Commission and the deductions made with the assistance of its engineers.

The New York Census of 1909 (60) was taken upon the county highways improved by state aid and also upon roads which the Commission then expected to improve as state or county roads during 1910. The observers were departmental employees of the grade of patrolman or laborer in most cases. The dates of the census were Sept. 1 and 15 and Oct. 1 and 15, 1909, over the roads proposed to be improved. Another census was taken by the New York department in 1914 during the summer when travel was supposed to be at its maximum. The observers were patrolmen working under the supervision of the division engineers and the dates selected were two specific Saturdays especially determined in each case. It is stated that "the average of these 2 days should give the information desired, namely; the volume, weight and character of traffic on the roads of the state, with a degree of accuracy sufficient for the purpose which is to determine the relation between work done and cost of maintenance. As a consequence the adaptability or economy of the existing road pavements and methods of maintenance can be determined."

Blanchard's Method (3) for taking a traffic census on ROADS is as follows: "After the classification of the traffic has been adopted, the methods of securing traffic data must be considered. As a practical, economical and efficient plan, the following method is proposed for adoption under average conditions for the season from Apr. to Oct. inclusive for country highways in the northern states. The traffic should be taken during four periods of three days each, one period being in Apr., May or June, one in July, one in Aug., and one in Sept. or Oct. As local conditions may dictate, either Friday, Saturday and Sunday, or Saturday, Sunday and Monday could be taken, thus insuring information relative to the usual abnormal Sunday motor-car traffic and, in some cases, the traffic above the week-day average on Saturdays, while the Friday or Monday traffic would give a fair indication of the normal week-day traffic. From a study of the meteoric records, it will be found that the climatic conditions are favorable to the adoption of the plan proposed. In the months from Nov. to March, inclusive, two 3-day periods would be taken in certain cases; one in Nov. or Dec., the other in Feb. or March. This distribution of the periods would furnish statistics of the normal traffic in this season and would also afford opportunity for a study of traffic detail and condition of the road during the winter season. In many cases only a month will be available in which to make all the preliminary investigations. Under these conditions the traffic should be observed for 3-day periods using three sets, one of Friday, Saturday and Sunday, and two of Saturday, Sunday and Monday, one period in the first week, one in the third, and one in the last week. The number of consecutive hours which should be taken during the day will depend upon local conditions and the period of the year when observations are made. In many cases 24 hr will be absolutely necessary, while in certain cases 8, 12 or 15 hr will be satisfactory. While it is feasible to lay down general recommendations relative to traffic census periods for country highways, in the case of city streets the plan adopted will vary in detail dependent upon local traffic characteristics and other conditions." See (7).

Connell's Method (24) for taking a traffic census on STREETS is as follows: "Observation points should be carefully selected, and at a sufficient number of points on the highways thruout the city to collectively be considered as representing the char-

acteristic traffic requirements on each general class of highway and on all of the several kinds of modern street and road pavements in general use. In order to obtain complete representative annual records it is desirable that during each year four separate census counts should be taken at each observation point, one count being made during each of the four seasons of spring, summer, autumn and winter. Each count should be taken continuously between 5 A.M. and 9 P.M., or during the entire 24 hr if so desired, on a consecutive Friday, Saturday, Sunday, and Monday, which days will provide data for two full business days, a half holiday and a whole holiday. In this connection it is important to note that, while city streets carry maximum traffic on business days, suburban and country roads carry their maximum traffic on Sundays and holidays, and vice versa, which condition is due primarily to the alternate suspension of business traffic in favor of pleasure traffic. The observers should ordinarily be on duty in two 8-hr shifts, working respectively from 5 A.M. to 1 P.M. and from 1 P.M. to 9 P.M. Under average conditions an observer should be stationed at each observation point, but if the volume of traffic or the number or extent of the details to be noted require two or more observers be assigned, it should be so arranged, as conditions may necessitate that each of the two observers will record exclusively the traffic going in one general direction."

15. Effects of Traffic

The Location is affected by the sources of the traffic and its destination (see Art. 1). It is also affected by the character and the amount of the traffic, all these in the same way as the location of a railway is affected by like considerations. If local traffic alone is to be accommodated, the location will be quite different from that where thru traffic is the main consideration. If both thru and local traffic are to be most efficiently provided for, then the location must be equally well made. Assuming, in illustration, that railway lines already exist in a locality, perhaps the most effective development of the transportation facilities for purely local traffic will be had by locating the improved highways radially from the railroad stations. On the other hand, if the local traffic is light because of the unproductive character of the country traversed by the railway, it is possible that the most important need of the community is the provision of an improved highway thru the district at approximately right angles to, or even closely parallel with, the railway. If, however, the railway facilities are insufficient for the development of the territory, it may that the greatest good will be had by the improvement of a highway far enough from the railway for the greater part of its length and yet connecting with it at one or more points, so as to open up prospective new territory and at the same time, provide for transportation thru the territory in question from outside points.

The Lines of a Highway are affected by traffic (see Art. 2) as will be evident when the conditions surrounding the different classes of traffic are examined. For instance, slow moving horse-drawn traffic can readily pass around much sharper curves than can fast moving motor traffic. Furthermore, in the case of the former, not so much warning of the approach of other vehicles is needed as in the latter case. Hence, the necessity for unobstructed vision for a reasonable distance at curves is not as great.

In 1908, the Permanent Int. Assn. of Road Congs. recommended a minimum radius of about 165 ft. In 1913, the importance of motor traffic having so enormously increased in the interim, the same body made (75) the following recommendations: "The radii of curves in roads used by fast traffic should, wherever practicable, provide the best possible and an unobstructed view, and that where this is not possible, the curve being of too short a radius, means should be provided whereby the approach thereto is in some

way clearly indicated." Where the traffic conditions are such as to encourage vehicles to follow closely in each other's tracks and to cause the excessive formation of ruts in the road, and consequently high cost for maintenance, these results can frequently be avoided by the establishment, as far as practicable, of curved lines for the highway. It is readily noticeable that at turns, unless they are too sharp, the tendency to tracking and rutting is not nearly so great as on the tangents.

The Grades to be established on a highway are affected also by the character of the traffic. See Arts. 8 and 10. If the traffic be mainly for pleasure, the economic disadvantages of heavy grades are not so perceptible as in the case of heavy commercial traffic conditions. Furthermore, with some kinds of traffic, a heavy grade, if established, will result in an irresistible demand for an expensive surfacing in order that the traffic conditions may be properly met. The cross grade or crown endurable by motor traffic is generally greater than that safely permissible under animal-drawn traffic, and if the latter class is considerable in any instance, it may mean that, for the sake of the flatter crown, a different kind of surfacing, with a consequent change in the cost, will have to be had instead of the crown and surfacing most suitable for motor traffic alone.

The Width of the Roadway to be provided is, within limits, determined by the traffic conditions (see Arts. 11 and 12). The necessary width, above a minimum, of the roadway for present or future traffic conditions will be determined by the count or estimate of the number of vehicles to be provided for, taking into consideration also their direction, speed and size. Their weight enters when the foundations and the character of the surfacing are to be decided. The width, beyond the minimum necessary for safely and economically sustaining one line of traffic, will depend on the frequency of passing vehicles. Hence it is desirable in the enumeration to separate the figures of the count into the number going in either direction, as well as to enable an estimate of the frequency of the passing of slow vehicles by faster ones going in the same direction, by classifying, in such a way as will enable the faster to be distinguished, the vehicles going in each direction.

Foundations of the Roadways are affected by traffic, because as it is the foundation which must ultimately carry the loads coming on the roadway surface, and as the supporting power of the foundation must be sufficient under the most favorable conditions likely to occur to safely resist these strains, it becomes necessary, in determining many of the questions concerning foundations, to know the kind and amount of the strains to be borne by it. If the traffic is to be mainly light pleasure vehicles, the natural soil when properly drained may be ample as a foundation. If the traffic is to consist of heavily loaded, narrow and hard-tired vehicles, a stronger foundation is probably necessary, unless a sufficient distribution of the strains set up by this traffic is delivered to the foundation thru an extremely coherent and more substantial surfacing. If the traffic is to comprise heavily loaded motor trucks, still stronger foundations may be necessary. Again if traffic conditions on the highway are likely to be severe during periods when the foundation is naturally in a worse condition to resist such strains, such as in the thawing periods during the winter, when perhaps heavy traffic of poles, ties and like products is to be expected, then greater precaution in preparing the foundation must be taken to provide proper drainage and to secure the greatest possible ability of the foundation to resist the destructive strains.

The Character of the Surfacing of the roadway will be affected by traffic conditions. See (26d). If horse-drawn traffic is the main con-

sideration, the proper regard for sufficient foothold for the horses must be had. If motor traffic should demand the greatest consideration, it may be necessary, for the sake of economy and the greatest general satisfaction, to disregard, to some extent, a lack of foothold afforded by the surfacing. If hard-tired vehicles form the bulk of the traffic, the character of the surfacing must be such as to resist successfully the abrasive effects of such traffic. Some types of surfacings are more seriously affected by peculiar forms of horses' shoes than are others. Under some traffic conditions, great care must be taken in selecting the surfacing to avoid the choice of one which will be quickly pushed into waves and ruts under the traffic. If pleasure traffic is the main consideration, then proper regard must be paid to securing sufficient resiliency and elasticity in the roadway surface. See (16b).

Maintenance Character and Costs are affected by traffic. In many cases, a certain minimum of traffic is required in order that the maintenance may be most satisfactory and economical. This may seem a strange statement but nevertheless it is true that traffic up to a certain amount is desirable on some surfacings to keep them in good condition. For instance, unless a water-bound trap rock macadam does get a sufficient amount of hard-tired traffic to produce by abrasion sufficient fine material to offset that lost thru the effects of wind and rain, the condition of the roadway surface will not be satisfactory and its maintenance will be expensive. For several years, the Mass. Highway Comm. paid from $50 to $75 per mile per year for the spreading of sand on the lightly travelled trap rock water-bound macadam roads of Cape Cod in order to prevent the macadam ravelling after the blowing away of the fine material from its surface. Again the sweeping effect of soft-tired motor traffic required the abrasive effect of hard-tired traffic to counteract it. The dislodging effect of horses' feet needs the rolling effect of wheels for preventing the ravelling otherwise inevitable. As before indicated, enough traffic on a road to insure some distribution of the effects is desirable to offset the tendency of less traffic to form horse paths and ruts in the roadway. For interesting discussions concerning the effect of traffic on roadway surfaces and especially the effect of wheels themselves see (7) and (25). See also Art. 16.

Some Conclusions Relative to Effects of Traffic (26b) may be quoted as follows: "A 12-ft water-bound limestone macadam will not support successfully travel aggregating 400 units per average day of 10 hr, and where 60% of the total travel is that of motors; such a road surface can be made to sustain such travel, with physical satisfaction, by treating it with Glutrin; such a road surface can be made to sustain such travel, with physical satisfaction, by giving it a surface treatment of cut-back Texas asphalt; an 18-ft water-bound, trap rock macadam is incapable of sustaining, without serious deterioration in a few months, travel aggregating 2500 units per average day of 10 hr, and where 90% of the total travel is that of motors; the surface treatment of such a road with a proper cut-back sludge asphalt, or a proper compound of water-gas tar, will enable it to sustain such travel, with physical satisfaction; a 24-ft bituminous macadam, of either limestone or trap rock, will sustain, with at least physical satisfaction, travel aggregating as many as 15 000 units per average day of 10 hr, and when more than 95% of the total travel is that of motors; a 14-ft bituminous macadam, of either limestone or trap rock, will sustain, with at least physical satisfaction, travel aggregating 5000 units per average day of 10 hr, and when less than 15% of the total travel is that of horse-drawn vehicles; a 12-ft width for the road metal is not economical where the travel aggregates more than 400 units per average day of 10 hr, nor is the 14-ft width economical where the travel exceeds 2000 units and the proportion of motor travel is more than 80% of the total; where high-speed motor travel forms a large proportion of the total, the unit width of travel lines should be considered as 9 or 10 ft, instead of 7 or 8 ft, as heretofore, because

of the greater clearance required for the safe passing of the units of such travel." For reference to similar expressions see Art. 16, (86) and (48).

16. Recent and Probable Changes in Traffic Conditions

The Determination of Traffic Using a Highway, while important, is not final as to the demands which will come on that highway when the latter shall have been improved. However, from the present use of a road, indication may be had as to its probable use when the improvement shall have been completed, and at any rate, the existing traffic conditions furnish the most reliable, if not the only, base from which future traffic conditions can be deduced. As yet no general agreement as to a method or formula for reaching such an estimate has been reached. The estimate of future traffic is, in any particular case, a matter of good judgment based on such information and records of previous and present traffic conditions as may be available. Every effort should therefore be made to secure all possible information on these lines before determining many of the questions which will come up for solution in connection with the proposed improvement. The improvement of a highway will increase the amount of traffic over it. This is the unanimous agreement from the comparatively few traffic records available. In some instances, this increase of traffic is caused more by diversion of traffic from other highways in the neighborhood, while in other cases, it is because a new and more pleasant route is furnished. Again, the improvement of a highway may further the development of the territory it serves and the increase of traffic may include the natural increase due to such development. Until more records from widely distributed sources and made up under a variety of conditions are available, it is not probable that formulas for estimating the probabilities as to increases of traffic resulting from the improvement of a highway will be developed. However, a careful study of such records as are available will throw some light on the problem.

The French Conclusions include the following: "The use of the National roads of France during the 9 years separating the census of 1894 and 1903 by traffic has grown appreciably heavier. The importance of transportation by horses has not ceased to grow in spite of the development of mechanical transportation. Notwithstanding the general increase there has been a light diminution of travelling by public carriage which can be explained by the development of railways and of bicycles." It should be remembered that in France nothing like the amount of construction of new highways or of new roadways is taking place that is going on in the United States. The problems there are mainly those of maintenance and not construction. The development of that country and consequently the increase of traffic to be expected for that reason is relatively negligible there, while in the United States this is an important factor.

The British Reports indicate the same general conclusions as the French and the same remarks apply thereto. Wood states (49) that the weight of the traffic in Fulham was 45% greater in 1914 than in 1909.

The Illinois Reports, based on the examination of traffic over mainly unimproved roads, show a larger annual increase in the traffic than do the reports from foreign countries. The average figures for 80 stations on 64 roads in Illinois are as follows:

Character of Traffic	1907	1910	1911	1912	Total Increase in Five Years	Average Annual Increase
Horse-drawn	166	182	198	160	21%	4.2%
Motor		8	10	41		

In Maryland, the figures published (26b) so far permit the following extracts: On the main road thru Druid Hill Park between Baltimore City and a growing residential suburban section, from which all commercial traffic is excluded, the traffic counts in 1904 and 1913, with the increases or decreases in percentages, were as follows:

Units of Traffic	Average per Hour 1904	Average per Hour 1913	Total Change in Percent	Average Annual Change in Percent
Ridden horses One-horse vehicle	34	7	− 80	− 9
Two- or more horse vehicle	10	0	− 100	− 11
Cycles	2	6	+ 200	+ 22
Motors	1	81	+8000	+889
	47	94	+ 100	+ 11

On Charles St., which is the main highway out of Baltimore City to the northern residential suburbs, the figures in 1906 and 1914 were as follows:

Units of Traffic	Average per Hour 1906	Average per Hour 1914	Total Increase Percent	Average Annual Increase Percent
One-horse vehicles	14	18	28	3¼
Two-horse vehicles	4	8	100	12½
More than 2-horse vehicles	0	1	....	....
Motors	4	268	7450	931
	22	295	1240	155

It should probably be stated that in the interval between the counts, the character of the surface of the street had been changed from that of an old stone turnpike to a modern bituminous concrete; that the roadway had been widened from 40 to 55 ft, and that a considerable development of the adjacent property and that to which the road was tributary, had taken place. On Park Heights Ave., the main road leading from Baltimore City out thru the suburbs and into the farming district, the counts in 1910 and 1913 were as follows:

Units of Traffic	Maryland Factor	1910		1913		Percent of Total No.	Increase in Moment
		No.	Moment	No.	Moment		
1-horse vehicle	2	6	12	24	48	300	300
2-horse vehicle	4	3	12	6	24	100	100
3-horse vehicle	6	0	...	1	6	100	....
4-horse vehicle	8	0	...	0	....	....	....
More than 4-horse vehicle	12	0	...	0	....	....	....
Totals		9	24	31	78	244.4	225
Motor-cycles	2	1	2	8	16	700	700
Runabouts	10	1	10	18	180	1700	1700
4 or 5-seat cars	20	6	120	118	2360	1866.6	1866.6
6 or 7-seat cars	40	3	120	67	2680	2133.3	2133.3
Drays	20	1	20	10	200	900	900
Totals		12	272	221	5436	1741.67	1898.5

In Massachusetts, where the roads have been in an improved condition for years, and where perhaps the factor entering into the increase of traffic and connected with the

development of property may not be so influential as in Maryland, the figures relative to the change of traffic are as follows:

Character of Traffic	1909 Census, 238 Stations			1912 Census, 156 Stations			Increase or Decrease in Percent	Average Annual In-
	Average Total Number per Day	Average Number per Day per Station	Percentage of Each Class	Average Total Number per Day	Average Number per Day per Station	Percentage of Each Class		
Motors								
Runabouts......	4 958 5	20 8	8 5	5 819.0	37.2	11	+ 79	+27
Touring cars	17 960.5	75 3	30 5	27 178 5	173 5	[illegible]	+130	+43
Trucks	.	.	..	1 800 0	11.5	3	..	. . .
Total motors	22 909 0	96 1	39.0	34 797 5	222.2	63	+131	+44
Horse-drawn vehicles								
1-horse, light	17 033 0	71.5	29.0	8 380 0	53.5	16	− 25	− 8
2-horse, heavy	11 762.5	49 3	20.0	7 458 0	47 6	14	− 3	− 1
2- or more horses, light.	1 006.0	4.2	2 0	556 0	3 6	1	− 14	− 5
2- or more horses, heavy.	6 205.5	26.0	10 0	3 870 5	24 7	7	− 5	− 2
Total horse-drawn	36 007.0	151.0	61 0	20 264 5	129 4	37	− 14	− 5
Totals of all kinds.		247.1			351.6		+ 42	+14

Increases in Severity of Traffic Other Than in Numbers of Vehicles are apparent from the records. On improved highways larger and heavier loads also are carried at greater speeds. Loads previously dragged laboriously at a slow walk, progress frequently at a trot over the smoother surfacings and the speed of motor vehicles becomes perhaps considerably increased.

The Larger Size and Weight of Loaded Vehicles using improved highways has often been noted and in many cases the new proposition to place a maximum limit on the weight of such traffic has appeared. The existence or probabilities of such restrictions, either direct from specific laws or ordinances or indirect as thru license laws tending effectually to restrict excessive loads must be investigated and considered before decisions concerning highway problems can be properly made in many cases.

The Average Speed of Traffic generally seems to have considerably increased. If, for instance, an estimated average speed per hour be assigned to each of the units in a census category and their product be divided by the total number of all the units, an average speed per hour for the total traffic may be obtained and compared with another average obtained in a similar way from a census at another date.

In the case of the Charles Street census given above, by assigning average speeds per hour as follows:

1-horse vehicle	8 miles per hr	Runabouts	15 miles per hr
2-horse vehicle	4 miles per hr	4 or 5 seat cars........	20 miles per hr
More than 2-horse vehicle	2 miles per hr	6 or 7 seat cars.. .. .	20 miles per hr
Motor cycles..	40 miles per hr	Drays.	10 miles per hr

to the units of the 1906 census, an average speed per hour for the whole traffic is found to be 8.7 miles. From the 1914 figures, it is found to be 17.4 miles or an increase of 100%. In the case of Park Heights Avenue, the average speed per hour of the total traffic is found to be in 1910, 13.2 miles, and in 1913, 19.6 miles per hr, an increase of 33.3%. In the case of the Druid Hill Park Road, the figures are: average speed per hour in 1904, 7.4 miles; in 1913, 11.7 miles; increase 44.6%.

The Increase in Combined Effect of Weight and Speed is illustrated by a comparison of the total figures in the traffic census table on Park Heights Avenue. It will be seen that the increase in moment is nearly 1900% while the increase in numbers is not over 1750%. The sub-totals show the horse-drawn traffic to have increased to a greater extent in numbers than in moment and a conclusion might be that some of the heavy loads, which in 1910 would naturally have been hauled by horses, have in 1913 actually been transported by motors, thus indicating a tendency already more or less recognized. In the case of Park Heights Avenue, the road had been completed just previous to the first traffic census in 1910, so that the increase there shown is probably not due particularly to any betterment of the roadway surface, but is more likely due to the development of the territory served by the road, and to the natural increase of traffic, especially by motors, during the period named, in this vicinity.

SELECTION OF SURFACINGS

17. Appropriateness and Availability of Surfacings

The Proper Selection of the Surfacing for a Roadway is of the greatest importance. See Sect. 24, (26c), (26i) and (26k). In the preliminary considerations, tentative selections of the road crust or pavement to be built from the list of those available must be made before many of the other details can be determined, or contemporaneously with such decisions. As has been stated by one or more prominent highway authorities, it is probably true that more mistakes have been made and more money wasted by the mistaken efforts to construct permanent roadway surfaces at high first cost than would have been the case had the selection of construction materials and methods been more widely made with reference to the use of cheaper methods and local materials and then proper maintenance accorded the results from these. The permanent road crust is a will o' the wisp and the importance of proper maintenance is daily becoming more appreciated. Hence a reaction has set in from the one-time demand for trap rock at any cost for use in broken stone macadam and the utilization of the local supplies of perhaps less tough stone has taken place with an advantage in the expense in the long run. The use of inferior stone in the bottom course of a road crust and the restriction of the use of more expensive stone is now a common practice. Developments in the use of gravel and recognition of its value in many cases when properly used has materially reduced the first cost of road improvement in many instances. The development of the use of bituminous materials in highway work has done much to bring about a great variety of road crusts and a consequent greater freedom for the selection of that crust most suitable in any particular case. Coincidentally the problem of making the proper selection in any case is rendered more complicated and the necessities for this proper selection are increasing with the general growing demands for efficiency. If the location, crust, drainage structures and other such items have been established as well as possible, and with what may be called permanent results, then conditions permitting, the maximum attempt may be made to secure permanence in the selection and construction of the road crust or pavement. This is especially desirable where the cost of the latter is met by borrowed funds. On the other hand, it may be extremely inappropriate to place a roadway surface with an expected long life and at a high first cost over a temporary grade or location, even tho the expenses for the pavement were to be met from the annual revenues of the locality. It is sometimes contended that all surfacing should be paid for out of the annual revenues

and never from borrowed funds, and there is a certain amount of justification to this argument. See (261).

Standards for Road Crusts and Pavements as well as for other highway details are issued by many highway authorities.

As editorially stated in Engineering and Contracting (29a): "It is perhaps somewhat unfortunate that the word standards should have been chosen to designate these plans. Strictly interpreted, the meaning would indicate that the standard design was the best design. This is by no means the case, nor is it intended to mean this. Standards are merely recommended designs which are to be adhered to unless conditions indicate that a variation in the design would meet them better. * * * And yet these standards are accepted as criterions by many engineers. * * * As a rule, they are designs prepared by engineers of wide experience and of prominence in their profession and they represent the crystallization of ideas tempered by mature judgment and years of observation. A young engineer and an old engineer, inexperienced in the class of work to which they refer, may compare and study them with profit. * * * There is, however, a grave danger attendant on the use of standards of any kind and the temptation is to neglect the detailed study of local conditions and use a standard structure. This often results not only in an unwarranted increase in the cost of a suitable structure, but may result in a type of construction which fits but poorly the location where used." See also (8).

Æsthetics and Local Environments will affect the selection of the surfacing or the tentative selections to be made. It is perhaps seldom that proper consideration has been given in the United States to the questions of appearances in this matter, especially on the public highways. In Europe, however, there are many striking examples of consideration of æsthetics in connection with the determination of many matters connected with highway work, including the matter of the selection of the surfacing. For instance, at Monte Carlo, the selection of the materials and methods for constructing the road was finally decided by the demand that the color of the finished roadways should harmonise with the architectural and natural surroundings. In some cases in the United States, the final selection of a light colored material, such as shells or white limestone for the road crust, has been brought about by the demand for the most suitable road crust that would reasonably withstand the traffic conditions and, at the same time, furnish a readily visible roadway thru heavily shaded stretches, especially where no provisions could be made for artificially illuminating the roadway at night. The choice between different colored bricks, or between a brick pavement and a bituminous pavement, has occasionally been finally made on the color basis. The selection of the type of a wearing surface may be decided in some cases by the value of the adjacent property or the assessment thereon.

Purely Local Conditions proceeding from the use or development of the abutting property may affect the selection of the surfacing. The proximity of a hospital or of a court room or other public utility, may demand the quality of noiselessness in a pavement with such force as to offset many, if not all, of the reasons for the selection of a different character of pavement, but one in which the characteristic of noiselessness is far less pronounced. Under some conditions, all the arguments for the selection of a certain character of road crust to meet the other local conditions properly have been set aside by the demand from abutting fruit growers for a road crust less dusty in character because of the serious injury which would be caused the fruit by the construction of the more dusty, even the less expensive, road crust. The general character of the use of the abutting property will affect the selection to some extent when other conditions permit a choice from several surfacings otherwise suitable. In residential sections, the

objections to the carrying on the feet of bituminous material into the buildings are generally far more noticeable than is the case in commercial districts. In retail districts, where frequent and irregular crossings of the streets by foot passengers, many of whom wear small shoes having thin soles and high heels, is most prevalent, the demands for a pavement that will everywhere afford a suitable footway, are much stronger than in wholesale districts, where special provisions for crossing at the intersections will suffice.

The Character of Labor Available for the construction of the surfacing may affect the selection. For satisfactory results, some pavements require especially trained and experienced laborers in the work, and if these are not available, the choice of such a pavement may be inadvisable, altho otherwise the selection would be most satisfactory. This frequently used to be the case in many instances with sheet-asphalt pavements, altho the growth in the general use of this pavement has resulted in greatly increasing the number and distribution of men competent for meeting the requirements. At present it is particularly the case with the small stone block pavement known as Kleinpflaster or Durax which for success requires to be most skillfully laid.

The Construction Season may affect the selection of the surfacing. In the first place, an element of risk for the contractors comes from the difficulty of determining with any degree of accuracy the effect of weather conditions on lost time, and consequently this consideration affects materially the price to be named for the work. Even when the probable cost has been determined for a variety of suitable surfacings, the tentative or final selections will be affected by the possibilities or probabilities, under the climatic conditions known to prevail in a locality, for satisfactory construction within the time limits imposed. The proper construction of a water-bound macadam road crust requires a subgrade sufficiently dry and firm to permit of thoro compaction by the roller and such freedom from extremely low temperature conditions as will permit the use of water in binding the macadam without the freezing of the wet or moist material. These conditions cannot be met successfully during long, continuous rainy periods, nor during certain months of the year in northern climates. The use of bituminous materials requires air temperatures above a minimum in each case, and freedom from an excessive moisture. In some localities, the desirable conditions may be difficult to obtain. The successful use of cement requires freedom from freezing conditions, and the presence of at least a minimum amount of moisture in one form or another.

The Plant Equipment available for both construction and maintenance may affect the selection. In the efforts for efficiency and economy has come a considerable increase in the use of machinery for highway work and the availability of such machinery, or the adaptability of the plant required for road construction to other purposes after the construction shall have been completed, will affect the probable cost and thus the selection to some extent. Again the availability of the machinery necessary for the maintenance of a particular form of construction and the expense incidental to the provision of such machinery, its operation, up-keep, depreciation and other unavoidable charges connected therewith, will materially affect the probable cost for the necessary repairs to such a surfacing and thus the question of this selection. It would be inadvisable to make a selection of a surfacing even tho economical in first cost, if because of the lack of the necessary machinery for its repair, or because of the high cost of repairs thru the proper provi-

sion of such machinery, idle or unavailable for considerable periods, the resulting maintenance would be extremely expensive or would not be continuous and efficient, but would be neglected and needed repairs allowed to go unmade for a considerable period.

The Presence of Street Railway Tracks within the limits of the surfacing may affect the selection, depending considerably in any case upon the character of the street railway construction. It is frequently considered advisable to provide a block pavement of some sort over the area occupied by the tracks, including the space between double tracks and for a limited distance beyond each outside rail, generally extending about to the opposite ends of the ties, because of the greater difficulties of maintaining satisfactorily a sheet pavement within this area. If the railway construction is of a light or flimsy character and consists of light weight rails, spiked to wooden ties, the latter being tamped with the natural earth found along the line, and the necessary lining up and surfacing of the tracks is more or less constantly going on, it will be folly to select an expensive surfacing for the roadway area, and one which, under other conditions, might be expected to have considerable permanence of character. Even where the track construction seems of a fairly good character and the disturbance of the roadway surfacing in the railway area is less frequent, it may be that the development of the traffic over the railway is rapidly bringing about the use of much heavier rolling stock, and the replacement of the track construction in a heavier and stronger form is only a matter of a relatively short period, or the frequency of repairs may considerably increase. In this case, too much permanence should not be sought in the selection for the railway area because of the desirability of avoiding ultimately unnecessary expense. In cases where the railway track construction is of the highest character, such as heavy grooved rails, bolted to steel or creosoted ties with a sufficient concrete foundation under the latter, it is permissible to go to considerable expense in the selection and construction of surfacing for the railway area in order that the greatest efficiency of the entire roadway may be had. Even in these cases, the paving of the railway area with blocks is often preferable to the laying of a sheet-asphalt over it, because of the unavoidable necessity of at least occasionally making openings into the area for railway purposes, and because of the general greater satisfaction with which such openings can be made and repaired in block pavements. See (58f).

The Kind and Amount of Traffic to be expected on the roadway will largely affect the selection of the surfacing (see Art. 15) and the inherent characteristic of the various kinds of surfacings, as developed by the traffic over them, must be considered in even the tentative selection of a road crust or pavement. For instance, the resonance and sound-reflecting power of cement-grouted brick pavements under certain traffic conditions may forbid their selection in some cases. For further discussion on these points, see Sect. 20 and (26d).

Provision for the Maintenance of Pavements in Railway Areas should be considered in this connection (see Sect. 23). Generally the maintenance of the surfacing in such areas is saddled on the railway authorities, but even where provision is properly made that such maintenance shall be under the supervision and to the satisfaction of highway authorities, the difficulties of securing the same kind of results for the maintenance of the railway area as are secured for the maintenance of the roadway outside the railway area are almost always insurmountable. Accepting as an axiom that all parts of the roadway space should present to traffic a surface equally inviting,

proper consideration should be given to the different kinds of surfacings available for both the railway area and for the balance of the roadway area so that this result may be secured, and to the probabilities, as well as the possibilities, for maintaining the surfacing in both areas so that uniformity of invitation to traffic for the entire railway area may be continuous. See also Art. 17 and Sects. 20 and 23.

The Scientific Selection of Road Crusts and Pavements is not yet provided for by any method supported by general agreement, even for any particular case. A brief statement here would be that an assumption is made that the suitability of a road crust or pavement may be divided into certain factors and that by assigning in any particular case relative values to each of these factors for the different crusts, a comparison of the totals so assigned will give a good indication of the comparative suitability for all of the road crusts considered. The following factors may be considered: first cost, maintenance, cost durability, ease of maintenance cleanliness, low tractive resistance, non-slipperiness, sanitariness, noiselessness, acceptability and favorableness. Tables of values assigned to these factors for different conditions are included in Sect. 24. There will be needed in connection with tables accurate information, from records uniformly kept, as to the cost of maintenance of the various kinds of pavement as developed and standardized, as to their behavior as to the other items or components of the tables under stated conditions of travel, so that values can be properly assigned, with as little guessing as practicable, to such components, for a comparison of different pavements under any particular travel which is known to be expected in a specified case. Such records are now being collected and will probably be available before long.

There exists an intimate connection between traffic conditions and the discussion as to selection of suitability of a road crust or pavement in any case. The importance of a proper determination and consideration of traffic conditions with a determination of the relation between traffic conditions and the factors listed above cannot be too strongly emphasized. For further discussion connected with the selection of roadway surfacings see Sect. 24, (2), (3), (16c), (18), (26k), (35), (37), (51), (65) and (72).

18. Maintenance Conditions as Affecting the Selection of Surfacings

Maintenance Provisions Existing or Probable will affect the decisions as to many points in connection with the construction or improvement of highways, as has been before mentioned, but they particularly affect the selection of the surfacing. See (26e), (26f) and (52). For instance, if ditches, culverts, or other waterways provided, are to be allowed to accumulate, for a considerable period, obstructing matter inevitably coming to them, the net capacity necessary to prevent washouts and to insure their efficiency will have to be secured by providing a greater gross capacity than would be the case were obstructions frequently and regularly removed. This often happens to be the case where road improvement is made by one authority, such as the state, and then maintenance of the improved roads rests upon the local authorities, such as the county or town, and is difficult of prompt enforcement by the state authorities. Again, if an agricultural territory, adjacent to a town or city, is by reason of the improvement of a road thru it changed into a residential suburban district, the run-off of storm water to and thru the waterways of the road will probably be hastened, and in case of considerable building on what was formerly

farm land, the waterways which would have been sufficient under the earlier conditions will be found inadequate under the subsequent ones. If provisions exist, or are likely to exist when an improvement shall have been completed, for regularly and properly cleaning the street surface, a different form of construction may be justified from that proper in a case where no such facilities are to be provided. For instance, the relative dustiness or slipperiness of unclean brick pavements or sheet-asphalt is considerably different, and this fact may prove a deciding element in the selection. Some road crusts will suffer much more severely than will others from the continued presence of snow and slush over them, and the probabilities for the prompt removal of such destructive agencies should be observed. Some pavements, such as sheet-asphalt, require special apparatus for properly repairing and cleaning them, and it may be that the lack of such apparatus and machinery and the improbability of its being provided will determine against the use of such pavement in many cases and for the substitution of some alternative pavement. Some surfacings require more prompt attention to repairs than do others if economy and satisfaction are to be had from their use. The neglect to repair promptly minor defects in a bituminous road crust may result in much more rapid deterioration of considerable areas of the crust than in the case of a gravel roadway or of a brick pavement. If the patrol system of maintenance prevails, or is likely to prevail, on the new road, it may be assumed that repairs will be promptly and efficiently made. If, on the other hand, what is known as the gang system of maintenance must be depended upon for repairs, it may be probable that considerable periods will elapse between visits of the repair gang, and that in the time between these visits minor defects will have the opportunity to become of the greatest concern, especially if the character of the surfacing selected is such that it demands peculiarly prompt attention to minor repairs.

Traffic Diversion, or the possibilities thereof, during construction and repair operations of the highway should be considered particularly in considering the question of the selection of surfacing, because of the improbability of construction or extensively repairing certain surfacings in the presence of traffic. Some surfacings, such as macadam, can be built and repaired without closing the road to the ordinary traffic. Bituminous surfaces may be under ordinary conditions, but, on the other hand, it may be necessary to close the road to traffic or to divert the latter to some extent during certain stages of this work. Concrete foundations and pavements usually require the entire closing of the roadway to all traffic during their construction, and this is also the case when the construction has reached the stage of laying the wearing course of a pavement.

Traffic Regulations, or the lack of control affecting the speed of traffic using the surfacing, will affect the selection to some extent, and the probabilities in this respect must be weighed when reaching decisions as to the character of surfacing to be selected as well as in deciding concerning the other details of highway work before mentioned. See Art. 2 and (43b).

Under Some Existing Local Conditions, a change may be in progress and the direction and extent of the changes may be so indeterminable that the wiser course in the selection of a road crust or pavement necessary to be laid at any time will be to select the cheapest pavement which will reasonably satisfy present conditions, and which can be most readily adapted to the new conditions as their crystallization outlines itself in the future. See (9) and (61)

Reasons for High Cost of Maintenance. Frequently a type of road surface or pavement has been condemned and declared out of date because the maintenance costs on it in a locality or state have proved too high. In many cases, it will be found that such a conclusion, if not absolutely incorrect under all the circumstances, is at least too broad, and that the conclusion which should have been reached is that an improper selection of type had been made for the case or cases in question. If an excessively high cost of maintenance for a roadway surfacing is established, the conclusion should be that one or more factors are responsible. An equation expressing the situation might be stated as follows: Excessively high cost of maintenance equals bad selection times poor construction times inefficient maintenance. Consequently, to have a good selection with a low cost for maintenance, values will have to be determined and assigned to the construction and maintenance factors for the proper solution of the above equation.

ESTIMATES OF COST AND REPORT FORMS

19. Estimates of Cost

Cost Considerations are almost inevitable in connection with any problems of highway work. In an engineering prescription toward a result, if a variety of solutions is practicable, a comparison of their costs becomes necessary for a wise choice to be made with due consideration of all factors involved. See (26b) and (26e).

A Proper Comparison of Costs necessitates figures compiled on the same or closely similar lines with sufficient explanation of the variations where such occur. So far standards for reporting costs are lamentably lacking and the mistake is frequently made of comparing cost figures which are so made up as to be worse than valueless for purposes of comparison. For instance, the price bid by a contractor for performing a unit of work which includes not only the cost of labor and materials but also rental and depreciation of machinery, interest on invested funds and profit to the contractor, is frequently compared with the figure obtained by totalling the actual expenditures for labor and materials used by a city department owning its machinery and without including any allowance for the latter, for overhead charges, or for profit. This is manifestly an unfair comparison. Even where allowances for machinery owned as above have been included in some instances, they have not generally been figured at a uniform rate and the comparisons have therefore been misleading. As such a large percentage of highway work is done by contract, it is wise, in using cost figures in the preliminary construction affecting the decision, to make sure that all the items naturally included by a bidder for the work are covered by the items. Such items as overhead charges and profit so included should be separately stated in order that comparisons of the cost records or estimates of probable cost can properly and safely be made with figures that have been, or are likely to be bid. When referring to reports of costs by other parties, the investigator should keep clearly in mind the usual deficiencies in these reports as above referred to. See (18), (26e), (31), (41) and (72).

20. Report Forms

The Establishment of Regular Forms for reporting information on many of the points above mentioned as of importance in preliminary investigations is practicable and convenient. By so doing, the desired information

is not forgotten to be secured and reported and the facts are uniformly collected and stated. Information on some of the points above mentioned will necessarily have to be collected by especially trained men, others perhaps than the resident or division engineers frequently accustomed to using the standard forms, and in these special cases, the matter desired is so peculiar to the case that a regular form for its collection and expression is impracticable of design for general use. Some of the data usually collected on these forms will also be turned in with the notes of the surveying parties, but if duplication thus occurs to some extent, no harm is done and the benefit of a check, or of different views from various parties, will be had. See Sect. 5.

A Set of Forms which have been used successfully for a number of years in the Maryland highway department, and which were adopted from an earlier form of the Highway Comm. are, for purposes of illustration, appended. For a very complete set of forms for reporting pavement history and traffic, discussed before the Can. Soc. C. E., see (23). For other report forms, see Sect. 24.

Maryland State Roads Commission

Preliminary Report of Engineer Inspector on ....Road
(Contract No.........) in......................County.
Road from..............................to..............................
Station........................to Sta..............................
Plan, profile, and cross-sections received............................, 19....
Road examined..., 19....

1. Location Lines, discussion of.
(If changes can be made so as to avoid unnecessary land damages, Engineer Inspectors are expected to recommend them.)

....

2. Local Materials, suitable for construction purposes.
(Also distance from nearest station on line.)

....

3. Grade submitted, discussion of, with recommendations.

....

4. Street Railway Tracks.
(Engineer Inspector will state whether the present alignment and grade are satisfactory, and, if not, what changes are necessary.)

....

5. Local Information.
Rate per day 2-horse teams and drivers..............................
Rate per day labor..............................
Distance from nearest railroad siding..............................
Distance from nearest wharf..............................
Depth of water at wharf..............................
Character of road to haul over..............................

....

6. Road-Bed, present character of, station to station.

....

7. Macadam Sections, discussion of.
(Engineer Inspectors are expected to recommend the width and thickness of macadam, which will be the most economical and satisfactory in each case. It is not necessary that the same section shall be adopted thruout the entire length of the road. When a change in section will result in a saving of stone, by taking advantage of existing conditions, such a change should be recommended.)

....

8. Borrow, material in suitable form, location and quality of, and average haul from line.

....

9. CULVERTS, BRIDGES AND CATCH-BASINS.
(All structures with a span greater than 6 feet will be classed as bridges. Engineer Inspectors will give such information as they can secure concerning drainage areas. When it appears to be necessary to obtain easements for the discharge of culverts on private land, mention should be made of the matter under this heading. Also give estimated depths for Bridge Foundations.)

....

10. UNDER-DRAINS, recommendations concerning.

....

11. V-DRAINS, recommendations concerning.

....

12. TREES, value of, for shade.

....

13. MATERIALS TO BE USED IN CONSTRUCTION, not otherwise enumerated.

....

14. PRICES recommended for use in the preparation of estimates and contracts:

Excavation or embankment of all descriptions, excepting ledge...	$..........................per cu yd
Excavation, borrow..............	$..........................per cu yd
Gravel..........................	$..........................per cu yd
Broken stone on cars............	$..........................per ton
Stone at crusher................	$..........................per ton
Shells..........................	$..........................per bushel

....

(In all cases show stations between which recommendations apply.)

15. REMARKS.

....

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SECTION 5

SURVEYS AND OFFICE PRACTICE

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FIELD AND OFFICE INSTRUMENTS

1. Surveying Instruments

Metallic Tapes are made in lengths from 25 to 100 ft and usually are graduated to feet and tenths. They are made of cloth in which is interwoven fine brass wire. These tapes should be used for rough measure-

ments only as they are easily affected by the weather. They are much more reliable, however, than cloth tapes which should never be used.

Steel Tapes may be obtained in almost any length desired up to 500 ft. The common lengths used for surveying are 50 and 100 ft. Tapes over 100 ft long are rarely used except for base line work. The 50 and 100-ft tapes are usually graduated to feet and hundredths continuously thruout their length. Sometimes, however, the 100-ft tapes are only graduated to feet except the first and last foot which are graduated to hundredths. The continuous graduations are much more convenient and there is less liability of error in reading the tape. Base line tapes usually only have two graduation marks, the initial and the final.

Where great accuracy in measurements is required, steel tapes should be standardized by comparing them with some known standard of length. The standard length of tape is thus established and its exact length can be figured for conditions other than those for which it is standard. Tapes are standardized by the U. S. Bur. Standards at Washington for a small sum.

Spring Balances are used to obtain a definite pull on the tape where an accuracy greater than 1 in 10 000 is required. Any form of hook balance is adaptable for the work provided it registers correctly, altho there are some forms made especially for this purpose.

Thermometers are attached to the tape where it is necessary to record its temperature. Special thermometers are made for this purpose.

Sight Rods or Range Poles are made of steel, iron pipe, or wood with an iron point, generally in lengths of 6 to 8 ft. They are usually painted with alternate strips of red and white so as to be easily distinguished against light and dark backgrounds.

Plumb Bobs are made in various shapes of solid brass or of hollow steel filled with mercury. They weigh from 6 to 70 oz. The lighter weights, 6 to 16 oz, are used for plumbing with the tape or for centering the instruments over points. The heavier bobs are used only in triangulation work.

Compass. The compass consists of a graduated circular box *b* (see Fig. 1), in the center of which is a magnetic needle supported on a pivot. The needle is provided with an attachment by means of which it may be lifted off the pivot. A sight standard *s* is fixed at each end of the plate which holds the graduated circle so that the line of sight corresponds with the north and south line of the circle. The compass is leveled by means of the two plate levels *a* and the ball bearing joint *j* which is attached to either a jacob staff or a tripod. Some instruments are provided with a small declination arc and vernier on the plate by means of which the declination can be turned off and the true bearings of the line read rather than the magnetic bearings. The box is graduated from the north and south points in each direction 90°.

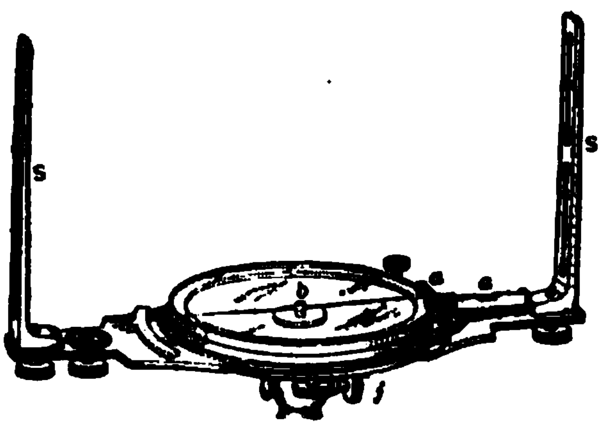

Fig. 1. Surveyor's Compass

Engineer's Transit. One form of engineer's transit is shown in Fig. 2. It consists of a telescope, with attached level, mounted on an axis which is supported by two standards fixed to the horizontal circle. A graduated arc or full circle is attached to the horizontal axis for reading vertical angles. The motion of the horizontal axis is clamped by means of the screw *a* and small movements are obtained by the tangent screw *b*. To the plate or standards are fixed two levels *l* at right angles to each other, which are

used in setting up the transit. The plate is composed of two circular plates, one set over the other. The standards are attached to the upper plate. The upper plate revolves on a vertical spindle which fits inside of a spindle supporting the lower plate. One plate is graduated into degrees and fractions of a degree while two verniers *v* are fixed on opposite sides of the plate carrying the standards. The motion of the upper plate is controlled by the clamp screw *d*, and the tangent screw *e*. The motion of the lower plate is controlled by the clamp screw *f* and the tangent screw *g*. The four screws *m* are leveling screws by means of which the instrument is leveled. The milled head *h* forms the base which is threaded inside to screw onto a corresponding piece composing the head of the tripod. A small chain *n* for holding the plumb bob is suspended from the bottom of the vertical axis and extends down thru the top of the tripod. The screw *o* on the telescope focuses the objective lens on the object. The capstan headed screws *r* hold the cross-hair ring while *s* is the eyepiece end of the telescope. The eyepiece is either erecting or inverting. A compass is fixed to the plate between the standards. The cross-hair ring is usually provided with one vertical wire and three horizontal wires. The two horizontal wires, one on each side of the middle horizontal wire, are the stadia wires.

Fig. 2. Transit

A Gradienter Screw is a screw with a graduated head that is substituted for the tangent screw of the vertical arc, and controls the motion of the telescope in the same manner. The head is divided into 50 parts and as the screw is turned the head passes over a scale graduated so that one revolution of the screw equals one space on the scale. The graduations on the head are so made that each division is equal to a movement of the horizontal wire of 0.01 ft at a distance 100 ft away from the instrument. A complete revolution of the head would mean a movement of the horizontal wire of 0.5 ft in a distance of 100 ft. By means of the screw the line of sight can be made parallel to any percent of grade desired. Thus to set the telescope to a 2.5% grade, level the transit and bring the bubble of the attached level of the telescope to the center, and clamp the horizontal axis. Turn the gradienter screw five complete revolutions and the line of sight is parallel to a 2.5% grade.

Instruments without the vertical circle or attached level on the telescope are called plain transits. Theodolites are instruments similar to the engineer's transit except they have no compass and are usually made more substantial, with larger horizontal circles graduated to give smaller readings.

To Set Up a Transit Over a Point. Set the tripod with the transit attached so that the plumb bob will come approximately over the point. Level the instrument by turning the upper plate so that one of the plate levels comes over a pair of diagonally opposite leveling screws. The other plate level will then be over the other set of leveling screws. Bring the bubbles of each of the plate levels to the centers of the tubes by manipulating the plate leveling screws to which they are parallel, taking care to screw down on one screw as fast as the other one is screwed up. When the instrument is level, loosen all four screws slightly and shift the instrument over the base until the plumb bob is accurately centered. Relevel and tighten screws and note if bob is still centered. If instrument is in adjustment, it will be level for any position as the instrument is revolved thru 360° azimuth.

Solar Attachment. A common form is a small telescope provided with cross-wires and attached level bubble. This telescope is mounted above

the telescope of a transit prepared to receive it so that the vertical axis of the small telescope is perpendicular to the horizontal axis and telescope of the transit (see Fig. 3). This instrument is used for finding the true meridian by observations on the sun. The method of work is described in Art. 10.

Plane-Table. The plane-table consists of a drawing board mounted on a tripod, and a ruler to which is attached a telescope provided with a vertical circle and stadia wires (see Fig. 4). The telescope with attached ruler is known as the alidade. The attachment between the drawing board and tripod is so constructed that the board may be leveled. This attachment also allows the board to be turned in azimuth thru a complete circle and has a clamp and tangent screw so that the motion can be controlled. A detached level tube, compass, clips for holding the paper on the board, scales, plumb bob and arm complete the outfit.

ment on Transit

Wye Level. The wye level consists of a telescope with attached level bubble provided with vertical and horizontal cross-wires, resting in two sockets or Ys. A socket is fixed to each end of a level bar which in turn is mounted on a vertical spindle. The spindle is supported by a base plate and four level screws similar to the arrangement in the transit and is attached to the tripod in the same manner. The telescope can be revolved in azimuth around its vertical axis and this motion is controlled by a clamp and tangent screw.

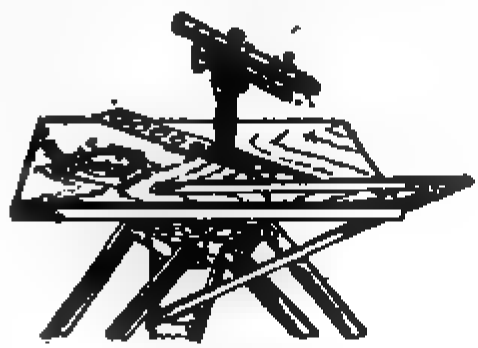

Fig. 4. Plane-Table

Dumpy Level. The essential difference between the wye and the dumpy level is that in the latter the telescope is attached to the level bar by immovable upright pieces instead of the wyes which are capable of adjustment.

To Set Up a Level. Set up the tripod with level attached and bring the telescope over a pair of diagonally opposite plate level screws. Bring the bubble to the center of the tube with this set of screws. Turn the telescope until it is over the opposite set of screws and bring the bubble to the center. Turn the telescope until it is over the first set of screws and see if the bubble is still in the center of the tube. If it is, the instrument is level, if not repeat the above operation until the bubble remains centered. The level screws are worked in the same manner as on the transit.

Three vs Four Level Screws. Both transits and levels are sometimes provided with three instead of four plate leveling screws. Three screws are generally placed on the heavier instruments used in triangulation work or precise leveling. To set up an instrument provided with three screws, turn the telescope until it is over two of them and bring the bubble to the center with these screws. Use the third screw to level the instrument in the direction of 90° to the line of the telescope in its first position.

Hand Level. The Locke hand level is a brass tube 6 in long having a small level mounted on its top to the left of the center near the object end. A frame carrying a horizontal wire is placed underneath the level. A reflecting prism that acts as a mirror is placed inside the tube directly below the level. Looking thru the eyepiece end of the tube, the reflection

of the bubble and wire is seen in the prism in one half of the aperture, while the other half is open to view the object sighted upon. The tube is placed to the eye and the object end is raised or lowered until the wire bisects the bubble, in which position the instrument is level. Both object and eye-piece ends are covered with plain glasses to prevent dust and dirt from getting into the tube.

Level Rods are made in several different styles. Self-reading rods are graduated so that they can be read by the instrument man. They are sometimes equipped with a target and vernier for closer readings. Except for precise work, the rods are made in sections and extensible so that when non-extended, the length will be from 4 to 6 ft, and, when extended, about 12 ft.

The Philadelphia Rod is of the self-reading extensible type with a sliding target. The rod is made in two strips, one sliding over the other, and is provided with clamps to hold the two strips and target in position. The face of both strips is graduated to feet and hundredths, and by means of a scale on the target and one on the back of the rod readings can be made to thousandths of a foot.

The New York Rod is of the extensible type with a sliding target, similar in construction to the Philadelphia rod. The lower strip is graduated on the face and the upper strip on the side, by means of fine lines, to feet and hundredths of a foot. This rod is not used as a self-reading rod. The target and side of the rod are both equipped with vernier scales so that readings may be made to thousandths of a foot.

The Boston Rod is of the two-piece extensible type. The target is fastened securely to one of the strips. For long rod readings the rod works on the same principle as the two previously mentioned. For short rod readings, however, the rod is closed and then inverted so that the target end rests on the ground. The strip holding the target is then moved up or down as the target would be in the case of the Philadelphia or New York rods. The sides of the rod are graduated to feet and hundredths of a foot and provided with vernier scales so that thousandths of a foot can be read. The Boston rod is obviously not a self-reading rod.

Self-Reading Rods are made in special styles, usually with the idea of making them more convenient to use. Such devices consist in making the rod extensible in three or four sections and in marking the graduations so that they are more readily observed. These rods are rarely equipped with a target.

Rod Tapes are manufactured which may be attached to any form of non-graduated rod.

Self-Computing Rods are of the extensible type. The graduations, however, are on an endless metallic tape. The rod is made in three pieces closing up to about 4½ ft. When the sections are placed together the metallic tape is passed over rollers at either end of the rod and the two ends are joined together on the back of the rod by a cinch strap. The graduations on the tape are in feet and hundredths but the graduations increase from 0 to 1 and 1 to 2 and so on downward on the tape instead of upward as in the ordinary level rod. The method of using the rod is described in Art. 17.

Precise Level Rods used by the U. S. Coast and Geodetic Survey are of the non-extensible self-reading type, without target, graduated to centimeters on one face. Metal plugs at 3-m intervals and a thermometer are set in the rod for purposes of detecting changes of length. The wood, of which the rod is made, is specially prepared by soaking it in paraffin. The length of the rod is checked up by comparing it with a standardized steel tape. Detachable rod levels are used to plumb the rod.

Stadia Rods are similar to level rods except that they are usually made with a larger face so the graduations can be more plainly marked. The value of the graduations on the rod depends upon the wire intervals of the transit. If the ratio of the focal distance of the telescope to the interval between the wires is 100, then a rod graduated to feet and hundredths of a foot may be used. For short sights any self-reading level rod can be used. Most transits unless otherwise ordered are furnished with stadia wires giving a ratio of 100.

2. Adjustment of Instruments

The Adjustments of the Transit, which should be made in the order given, are as follows: Parallax, plate level bubbles, line of collimation, horizontal axis and attached level bubble.

Parallax is a perceptible movement of the cross-hairs over the image of the object, when the eye is moved slowly from side to side at the eyepiece end of the telescope. Correct by pointing the instrument to the sky and focus the eyepiece until the cross-hairs are distinct, then point on any object and focus objective. If any movement of cross-hairs over the image still exists, repeat the above operation until it is eliminated, then the image of the object falls in the plane of the cross-hairs.

The Plane of the Plate Level Bubbles must be parallel to the horizontal plate. Level the transit in the ordinary manner by bringing one of the bubbles parallel to a pair of diagonally opposite level screws and making the bubbles come to the center of the tubes. Turn the instrument through 180° horizontally and note if the bubbles remain centered. If they do, the plate level bubbles are in adjustment and the graduated circle is horizontal in every position. If the bubbles do not remain in the center, correct by bringing them half way back to the centers by means of the leveling screws of the transit and the rest of the way back by means of the capstan screws at the end of each level bubble tube. Repeat the above test and correction until the adjustment is accomplished.

Line of Collimation, or line of sight, should be perpendicular to the horizontal axis of the telescope. First, the vertical cross-hair is made perpendicular to the horizontal axis. The instrument is set up and leveled. A point is bisected and the bottom plates clamped. The telescope is now revolved in altitude or about its horizontal axis and if the vertical wire still continues to bisect the point, no correction is necessary. If not, loosen the capstan screws holding the cross-hair ring and rotate the ring until the vertical wire and point remain in coincidence as the telescope is moved in altitude. Then tighten the screws holding ring. Next set up the transit on a level stretch of ground. Set a stake about 300 ft distant. Clamp all horizontal motions and center the cross-hairs on a point a in the stake. Reverse or plunge the telescope and center the cross-hairs on a point b in another stake set about the same distance from the instrument, as a. Unclamp the horizontal motion and revolve the instrument in azimuth and set on a again. Clamp and reverse the telescope. If the cross-hairs now center on b, the line of sight is perpendicular to the horizontal axis. If cross-hairs do not center on b, set a third point c opposite b where the line of sight does come. Measure the distance b to c. Bring the line of sight one-quarter of the distance $b\ c$ from c towards b by manipulating the adjusting screws which hold the cross-wire ring. Then by the plate tangent screw bring the line of sight to a point just half way between c and b. Repeat the test and correction until the adjustment is made.

Horizontal Axis. The horizontal axis of the telescope must be parallel to the plate. Set up the transit near some high structure and, with the horizontal motions clamped, sight the telescope on a point a near the top of the structure. Depress the telescope and set on a point b on the line of sight near the base of the structure. Unclamp and revolve the instrument thru azimuth and, with the telescope reversed, again set on a and clamp. Depress and sight towards b. If the cross-hairs center on b, the horizontal axis is parallel to the plate. If the transit is not in adjustment set a point c opposite b where the line of sight falls and measure distance $c\ b$. Move the line of sight to a point half way between c and b by means of the adjusting screw at the ends of the horizontal axis of the telescope. Repeat the test and correction until the adjustment is made.

Attached Level Bubble. The plane of the level bubble attached to the telescope and the line of sight must be parallel. The test for adjustment is made by the two-peg method. Drive two stakes, a and b, about 300 ft apart on a fairly level piece of ground. Set up the instrument about 1 ft from a and level the telescope by the attached level. Hold the rod on a and take a reading x_1. This reading is usually obtained by pointing the eyepiece at the rod and sighting thru the objective end of the telescope, noting where the center of vision strikes the rod. Next sight on b in the ordinary manner with the telescope level and obtain a road reading of y_1. Then set up instrument about 1 ft from stake b and obtain rod readings y_2 and x_2 on b and a respectively. If the attached level is in adjustment, $x_1 - y_1 = x_2 - y_2$ or $x_1 - x_2 + y_2 - y_1 = 0$. If not in adjustment with instrument still near b, hold the rod on a with the target set to read, $x_2 + \frac{1}{2}(x_1 - x_2 + y_2 - y_1) = \frac{1}{2}(x_1 + x_2 + y_2 - y_1)$. Set the horizontal cross-hair on the target by means of the plate leveling screws and then bring the bubble of the attached level to the center of the tube by means of the adjusting screws at the ends of the tube. Repeat the test and correction until the adjustment is made.

The verniers of the vertical arc may be made to read zero after the above adjustment for the attached level bubble has been made. With the instrument and telescope level, bring the zero of the vernier and arc into coincidence by means of the vertical tangent screw. Slightly unloosen the screws that hold the vertical arc to the horizontal axis, level the telescope again and move the arc until the zeros of the arc and vernier again coincide. Repeat the above operation until correct. If this adjustment is not made, the index error of the arc may be noted and applied to the measurement of all vertical angles.

The Adjustments of the Wye Level are as follows: Parallax, cross-hairs, level bubble and wye adjustment.

Parallax is corrected in the same manner as for the transit.

Cross-Hairs. Set up the level and bisect a point. Revolve the telescope in azimuth and see if the point is bisected by the horizontal wire thruout its length. If not, loosen capstan screws holding cross-hair ring and rotate the ring until the point remains bisected by the horizontal wire as the telescope is revolved. Next loosen the telescope in the wyes and bisect a point with the cross-hairs. Rotate the telescope 180° in the wyes and note if the point is still bisected. If not, move each cross-hair separately by means of its proper screws half way back to the point. Repeat test and correction.

The Level Bubble may be adjusted in the same manner as the attached level bubble on the transit. A more convenient method is as follows: Set up the instrument and bring the telescope over two of the leveling screws. Focus the objective on a point about 300 ft distant. Take the telescope out of the wyes, reverse it end for end and replace it in the wyes. If the bubble remains in the center, no adjustment is necessary. If not, bring the bubble half way back to the center by means of the plate leveling screws and the remainder of the distance by the capstan screws at the end of the tube. Repeat operations until the adjustment is made. To make the axis of the level tube parallel to the axis of the telescope, loosen the clips holding the telescope in the wyes and rotate the telescope about 20° in the wyes. If the bubble has the same reading as when the telescope is in its normal position, no correction is necessary. If a correction is necessary, move the end of the tube by means of the horizontal capstan screws at one end and repeat the test and correction until the adjustment is made.

The Wye Adjustment consists in making the horizontal plane of the line of sight perpendicular to the axis of the instrument. Level the instrument and turn the telescope thru 180° in azimuth. If the bubble remains in the center of the tube the instrument is in adjustment. If not, bring the bubble half way back to the center by the capstan screws which hold the wyes to the level bar and the rest of the way to the center by the plate leveling screws. Repeat the above operations until the adjustment is made. If in level work the bubble is centered each time before a sight is made, the wye adjustment can be neglected.

The Adjustments of the Dumpy Level are as follows: Parallax, cross-hairs and level bubble.

Parallax is corrected in the same manner as for the transit.

Cross-Hairs. Set up the level and bisect a point. Note if the horizontal wire continues to bisect the point as the telescope is revolved in azimuth. If not, loosen the capstan screws holding the cross-hair ring and rotate the ring until horizontal wire remains in coincidence with the point as the telescope is revolved.

The Level Bubble should be in the center when the line of sight is horizontal. Set up the instrument with the telescope over two of the plate screws and bring the bubble to the center of the tube. Revolve 180° in azimuth and if the bubble remains in the center, the instrument is in adjustment. If not, bring it back half way to the center by the two plate leveling screws and the rest of the way back by the capstan screw at the end of the level tube. Repeat the operations until the adjustment is made.

The level bubble and the line of sight must be parallel. The test for this adjustment is made in the same manner as for the attached level bubble on the transit. If the instrument is not in adjustment, the correction is made the same way as in the transit except that in making the line of sight coincide with the target, it is done entirely with the adjusting screws holding the cross-hair ring. The plate level screws or the capstan screw at the end of the level tube are not touched.

The Hand Level is adjusted as follows: Drive two stakes, a and b, about 100 ft apart on fairly level ground. Hold the level a distance x above a and with the wire bisecting the bubble sight on a rod held on b, giving a rod reading y. Go to stake b and

with the level held a distance y above b and the wire bisecting the bubble, sight on a. If the instrument is in adjustment, a rod reading x_1 equal to x will be obtained. If not in adjustment, correct by bringing the horizontal wire into coincidence with a point which is $x + \frac{1}{2}(x_1 - x)$ above a, when the instrument is held a distance y above b. The horizontal wire is moved by means of the adjusting screws under the level bubble.

3. Verniers

The Vernier is a small auxiliary scale used with the main scale for the purpose of determining fractional parts of the smallest divisions of the main scale. In Fig. 5 is shown a vernier for a linear scale, a type used on some level rods. The scale to the left is the main scale and that to the right the vernier. Verniers are either direct or retrograde. Since the latter type is rarely used on surveying instruments only the direct vernier will be described. Referring to Fig. 5, the vernier scale is divided into 10 equal parts which are equivalent to exactly 9 of the smallest divisions of the main scale. Each division on the vernier is then just 0.9 of one of the small divisions of the main scale. With the zero of the vernier in the figure at 7 of the main scale, point a on the vernier comes just 0.1 below b on the main scale, c comes 0.2 below d and so on. If the zero of the vernier is moved just 0.1 above 7 of the main scale, the first division on the vernier will be in coincidence with b on the main scale. If the zero of the vernier is moved 0.2 above 7, the second division on the vernier will come opposite d on the main scale. If the main scale is considered to be divided into feet and tenths, the reading of the zero of the vernier for this last position of the vernier will be 7.02. The rule for reading a direct vernier is to read the main scale to its smallest graduation up to the zero of the vernier and then read along the vernier to the mark which coincides with a mark of the main scale and add the reading of the vernier to the reading of the main scale.

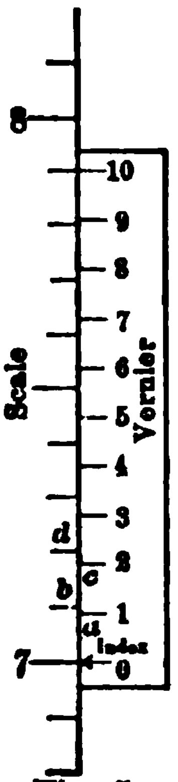

Fig. 5. Linear Vernier (3)

The Value of a Division on the Vernier or least count of the vernier is found by the following rule: Divide the value of the smallest division on the main scale by the number of divisions on the vernier between coincident marks, when the zero of the vernier is brought into coincidence with a division of the main scale. Applying the rule to Fig. 5, the value of a small division of the main scale is assumed to be 0.1 ft and there are 10 divisions on the vernier between coincident marks with the zero of the vernier as shown, hence the least count is $0.1/10 = 0.01$ ft.

Verniers on Transits are constructed on the same principle and are called single or double. A double vernier is one which can be read in

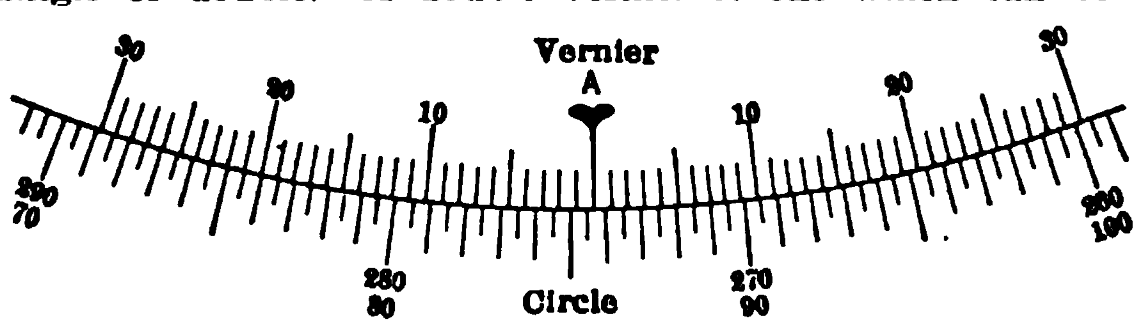

Fig. 6. Transit Vernier (3)

either direction. It is a direct vernier and is always read in the direction in which the angle is increasing. A single vernier is numbered from zero at both ends. In using a single vernier on a transit, the zero of the vernier

must be set with the zero of the scale so that the vernier reads in the same direction that the angle is to increase. Fig. 6 shows a double vernier common to transits. The least count of the vernier is found as previously described. In this case the smallest reading of the main scale is 30′. If the zero of the vernier is made coincident with a division of the main scale, it will be found that there are 30 divisions on the vernier between coincident marks, hence the least count is 30/30 or 1′. The angle in the figure, read in a clockwise direction, is 274° plus 23′ on the vernier, or 274° 23′. In the opposite direction, its value is 85° 30′ on the main scale plus 7′ on the vernier, or 85° 37′.

4. Drafting Instruments

Some of the special instruments adaptable for the office work are described below.

Straight-Edges. Steel straight-edges are more commonly used in plotting the work than T-squares. They are made in several different sizes from 15 to 72 in long.

Large Sized Triangles are useful, especially for drawing long perpendicular lines.

Simple Curve Templates of wood, rubber, metal or celluloid are made with radii, varying from 1.5 to 60 in. These are useful in drawing in curves between the tangents instead of using a compass.

Cross-Section Templates may be made from stiff material, preferably from a piece of a transparent celluloid triangle. The template is cut on lines conforming to the shape of the cross-section of the highway and is used in plotting the finished section of the highway on the original cross-sections so that the estimate of earthwork can be made. Sometimes the template is cut out, as in Fig. 7, to correspond with the subgrade trench. This form is more convenient to use than one cut to finished grade over the trench, since the cuts and fills have to be computed to the line *a b c*.

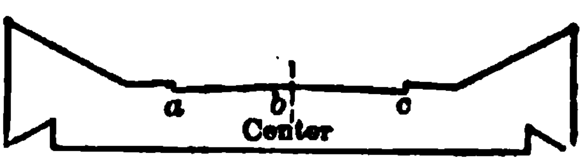

Fig. 7

Protractors are made of different materials and in various styles. Those of steel with a movable arm and attached vernier, by which angles may be laid off as close as 1′, are useful for checking up the plotting of the transit line.

A Convenient Scale, see (9), for plotting the topography is shown in Fig. 8. It should be made of transparent material and be graduated to the scale of the map. The line *a b* is made coincident with the transit line and plus stations may be scaled off by setting the proper graduation of the scale *a b* over a full station on the transit line. The 0 of the scale *a b* will then be at the plus station and perpendicular offsets either side of the line may be plotted on the scale *c d*.

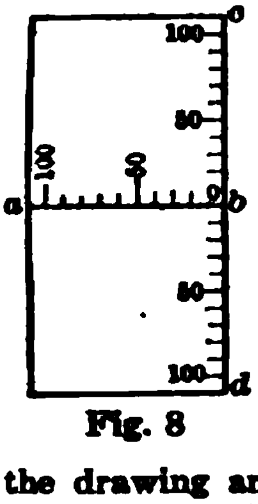

Fig. 8

The Planimeter is an instrument used for determining areas. Planimeters are made in three different styles, known as the polar, suspended and roller planimeter. Only the POLAR PLANIMETER and its method of use will be described since this is the type most commonly used. The polar planimeter consists of two arms hinged at a common point. The arms may be of fixed length or one of them may be adjusted to varying lengths by means of a graduated scale marked upon it. At the outer end of one arm is a needle point to be fixed to the drawing and about which the whole instrument revolves. To the outer end of the other arm is fixed a tracer point. The tracer point will always be found on the extensible arm if the instrument is adjustable. A small graduated wheel with vernier attachment and revolution counter is hung from the arm carrying the tracing point but at the opposite end from which the tracing point is fixed. The planimeter when in use rests on three points, the needle point, the tracer point and a point in the circumference of the graduated wheel. The instrument is used by placing it on the sheet near the area which is to be determined in such a position that when the needle point is set, the area can be outlined by the tracer point. The outer edge of the area to be determined is then traced over with the tracer point until a complete circuit has been made. The graduated wheel revolves as

the tracer point is moved and the difference in its initial and final reading registers the area of the figure. If one of the arms is adjustable, the arm can be set to correspond with different units of measurement. If the arms are both fixed, the instrument is made so as to read square inches or square centimeters. For highway work an instrument with fixed arms reading to square inches is a convenient form to use. Tables may be prepared converting square inches read by the planimeter into any other scale desired so that the desired area for any planimeter reading can be quickly found from the table. If the planimeter is placed on the drawing so that the needle point comes within the area, then a correction has to be added to the area obtained from the instrument readings. This correction, called the area of the zero circle, is constant for each instrument and is furnished by the maker. If the needle point is placed outside of the area to be determined, no correction is applied. Large areas that cannot be covered at one setting of the instrument may be found by subdividing them into several smaller areas of convenient size. See (2), (4) and (14).

Pantograph. A pantograph is an instrument consisting of a framework of arms so joined together that the motion of two points *a* and *b* of the framework is the same in outline, but different in amount. The instrument is used to enlarge or diminish the size of maps and by means of scales on the framework any relation between the size of the original map and that desired can be obtained. The instrument is placed on the sheet containing the drawing with the scales properly set and the tracing point *a* is moved over the different lines of the drawing. The marking point *b* will at the same time trace out corresponding lines on the same or another sheet but at the scale desired. See (2), (4) and (14).

Rubber Stamps for marking titles on plans and tracings are to be recommended, where the wording of the titles is of some standard form. Neat work can be obtained by using stamps and much time saved.

Drawing Tables. On account of the size of road plans, tables 4 by 12 ft are, in many cases, necessary if the plan is to be laid out at its full length on the table.

PLANE SURVEYING

5. Angular Measurements

To Measure an Angle with a Transit. Consider the angle *a o b* in Fig. 9. Set up the instrument and carefully center it over point *o*. Make the zero of the vernier coincide with the zero of the horizontal scale. This is done by making an approximate setting with the plates loose, then clamping them and making an accurate setting with the plate tangent screw. With the lower motion unclamped sight the telescope on *a* and set the intersection of the cross-hairs exactly on *a* by means of the clamp and tangent screw of the lower motion. Unclamp the horizontal plates and point the telescope on *b* and make a careful centering using the plate clamp and tangent screws. The angle *a o b* may now be read from either vernier. If it is desired to repeat the angle without setting the horizontal scale to zero again, unclamp the lower motion and sight on *a*, using the lower motion clamp and tangent screw. Turn the angle again and set on *b* as before. The angle read now from the verniers will be twice the first and if divided by two will be angle *a o b*.

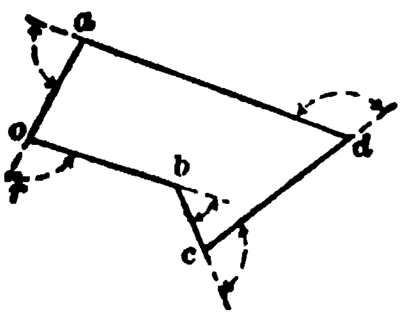

Fig. 9. Closed Traverse

A Traverse is run with the transit by setting up the instrument at intersections of the sides of the traverse, points *o b c d a*, Fig. 9, and measuring the angles at the intersection as described for angle *a o b*. The side lengths *a o*, *o b*, *b c* and so on are measured with a tape. If a traverse is laid out so that the last point of the traverse is the same as the starting point, it is called a closed traverse. The field measurement of a closed traverse may be

checked by calculating the error of closure (see Arts. 6 and 20). Exterior angles or deflection angles, as indicated on Fig. 9, may be measured instead of the interior angles. To do this, however, the telescope of the transit has to be reversed or plunged. If the instrument is out of adjustment with respect to the line of collimation, the angle will be in error unless the angle is repeated and the mean value taken. For example, to measure the exterior angle *r o b* with the instrument at *o*, sight on *a* with telescope in its direct position, attached level under telescope, plunge telescope and sight on *b* and read angle *r o b*. Now sight on *a* with the telescope in its reversed position, attached level over telescope, plunge and sight on *b* and read angle *r o b* again. The mean of the two angles will give correct value for *r o b* even tho the adjustment for collimation has not been made. The method of running a traverse line which does not close is the same as for transit line (see Art. 13). See also (4), (14) and (17).

The Magnetic Bearings of the sides *a o* and *a b* would be obtained as follows: When the transit is at *o* and the telescope is pointed at *a*, release the needle of the compass and, when its motion stops, read the north end of the needle as, for instance, N 30° 40′ W. Read the compass needle in the same manner when the telescope is pointed to *b* and suppose the bearing was N 20° 10′ E. Remembering how the scale of a compass is graduated, it is an easy matter to calculate the angle *a o b*. In this case it would be the sum of the two bearings, or 50° 50′. In running traverses with a transit, bearings of the sides should always be taken as a check on the angle between the sides.

6. Triangulation and Traverse Systems

Surveys which cover a large area, such as state or city surveys, should be referenced to points established by triangulation or some other accurate method. Sufficient points which have been established by the U. S. Coast and Geodetic Survey in its triangulation work may be found within the state or city limits to furnish a system on which the rest of the work can be based. If such points cannot be obtained, a triangulation scheme should be planned so as to provide over the area points whose precise positions are known. For a city survey these points should be between 2000 and 5000 ft apart. Closed traverses are also employed to control the work of the survey. This method, however, is not so accurate as a triangulation scheme, since in balancing a traverse any error which has been made in the survey is distributed within the traverse. Briefly, the traverse method is to run a system of closed traverses and adjust them until sufficient points accurately located are established to serve as a control for the rest of the survey.

In making a topographical survey of Staten Island, N. Y., by this method, the traverses were limited to 10 000 feet in perimeter and were as nearly square as possible. Each section was made up of ten or more traverses which were adjusted one to another commencing with the one having the largest error of closure.

The Triangulation System. The form of the system, the refinements and the instruments used in measuring the angles and base lines will depend upon the extent of the survey, the topography of the country and the purpose of the survey. The system may be composed of a simple chain of triangles, a chain of polygons, a chain of quadrilaterals with the addition of diagonal lines or, in an extensive survey, a combination of the three systems. The most accurate system is the quadrilateral system as it affords the greatest number of checks in proportion to the work done. The figures in the scheme should be so developed that no triangle contains

angles less than 20°, particularly in those triangles connecting the base line with the main system. See (4), (7), (10a), (24a) and (24b).

Triangulation schemes are separated into three systems by the U. S. Coast and Geodetic Survey, known as primary, secondary and tertiary. This classification is made with reference to the size of the triangles and the methods used in measuring them. In the primary system, the length of the sides may vary from 10 to 150 miles. The secondary system consists of triangles from 5 to 25 miles on a side which are developed from sides of the triangles in the primary system. The methods of work in both of these systems require about the same refinement and accuracy. The tertiary system is developed from the sides of the triangles composing the secondary system and points established by this system are located for the convenience of the topographical work. The location of points on the tertiary system does not demand the accurate work required in the other two systems.

Base Line. In any triangulation scheme it is necessary to measure the length of one or more lines in the system called base lines. All other measurements are angular measurements. Base lines can be measured with great accuracy and serve to check the results of the rest of the work. They should be introduced into the system as often as practicable: In primary work, say every eighth or tenth figure; in secondary or tertiary work, at the beginning and end of the system when separated from primary work. The length of base line is variable. In primary work it varies from 4 to 10 miles and even more, usually being 1/6 to 1/4 of the sides of the primary angles, while in tertiary work it may be 1/2 mile or less. Base line sites should be chosen with great care and the scheme for connecting the base line with the triangulation system should be carefully developed. The net of triangles connecting the base line with the main scheme of triangulation usually consists of a series of quadrilaterals with their diagonals intersecting at right angles, the length of the diagonals increasing in such a ratio that two or three sets of quadrilaterals are necessary in stepping up from the base line to the main triangulation. See (4), (7), (10a), (24a) and (24b).

The Instruments Used for triangulation and traverse work previously outlined differ depending upon the accuracy desired and the extent of the work. See (4), (7), (10a), (24a) and (24b).

Instruments for Measuring Angles. In extensive triangulation work such as is carried out by the U. S. Coast and Geodetic Survey, the angles are measured in the primary and secondary systems by means of direction instruments, the circles of which are 10 to 12 in in diameter and graduated to 5′ divisions. The fractional parts of the divisions are read by means of micrometer microscopes attached to the instrument. On work of lesser importance, repeating instruments are used. Repeating instruments are theodilites graduated so that angles may be read either to 5 or 10″. On small surveys angles in the triangulation system may be measured with sufficient accuracy with the engineer's transit having a 6 in circle and graduated to read to 20 or 30″.

Base Line Apparatus. In primary or secondary triangulation measurements are now generally made with 100-m steel tapes of small cross-section, 6.34 mm by 0. 47 mm, supported upon stakes or tripods. A spring balance is attached to one end of the tape for registering the pull. The temperature of the tape is usually recorded by means of thermometers tied to the tape. It is necessary that the tape be compared with some known standard of length before being used so that its exact length may be computed. In small surveys 100-ft standardized steel tapes are sufficiently accurate.

Temporary Signals are erected over the points of the system during the work of the survey so that they may be observed from other points in the system as desired. On short distances, guyed or braced masts are used. Heliotropes are used for signals on sights over 15 miles in length. When observations are made at night, acetylene lamps are used for signals. As far as possible, the principal stations are located on high and prominent points. In perfectly flat country, the curvature of the earth's surface prevents long sights being taken between two points unless the position of

the observer and signal sighted on are a sufficient distance above the respective points to overcome the difference in height due to curvature. Towers, the height of which depends upon the distance between the two points, must be erected over the points in order that the line of sight be unobstructed. Towers are also used in some instances to avoid expensive work that would otherwise be required in clearing. See (4), (7), (10a), (24a) and (24b).

Angle Measurements are made in sets. With the direction instrument, at each set up, a set comprises reading the directions of the signals to be sighted upon in order from a pointing at one of the signals as a reference. The telescope is then reversed and the directions are read in the reverse order. The U. S. Coast and Geodetic Survey require 16 sets for primary work, 5 to 10 for secondary and 1 set for tertiary. With a repeating instrument a set usually comprises measuring each angle 6 times with the telescope direct and 6 times in reverse direction with the telescope reversed. The refinement necessary to adopt in measuring angles depends entirely upon the extent and character of the work. In measuring the angles of the primary traverses in making an accurate topographical survey of the Borough of the Bronx, New York City, 2 sets of 6 repetitions each were taken closing the horizon so that the closing reading was within 10″ of 360°. See (4), (7), (10a), (24a) and (24b).

In primary and secondary triangulation observations of angles at any station should be distributed over different parts of the day in order to reduce to a minimum the errors arising from refraction. Cloudy days or times during the late afternoon are favorable for making accurate observations. It is essential that the instrument be carefully centered over the point and that pointings be made with rapidity consistent with good bisections. Proper support must be given to the legs of the tripod so that no movement of the instrument will take place during the observation. When it is impossible to set the instrument exactly over a station, its position should be carefully referenced to the station by angle and distance so that its eccentricity may be calculated and the observations reduced to the center of the station.

Base Line Measurements. Preparatory to measuring the base line it is necessary to clear the site and establish the two terminal points by means of permanent marks or monuments. Stakes are then driven along the line at intervals of 25 to 50 ft and nails are set in the sides of the stakes at the proper grade to support the tape. The stakes where the tape ends will fall have pieces of zinc nailed to them to facilitate marking the position of the end graduation of the tape. Measurements are made in the ordinary way with the following exceptions: The tape is supported at intervals thruout its length on the nails; a spring balance is attached to one end of the tape and a definite pull, usually about 16 lb, is given to the tape; mercurial thermometers graduated to half degrees, two to a tape length, are suspended from the tape and are read before and after each measurement with the tape is made. At least two independent measurements of the base line are made and preferably four or more, depending upon the conditions encountered. More accurate work can be attained on cloudy or rainy days than at other times since the temperature of the air and the tape correspond more closely. See (4), (7), (10a), (24a) and (24b).

Base Line Computations. The following corrections must be applied to the base line measurements to determine the exact length. See (4), (7), (10a), (24a) and (24b).

Correction for Temperature is obtained by the formula $Lc\ (d - d_0)$ in which L is the standard length of tape, d_0 the temperature at which the tape is standard, d the temperature of the tape at time of observation and c the coefficient of expansion of the material of which the tape is composed. The correction should be added algebraically to the standard length of tape.

Correction for Sag is obtained by the formula $Lg^2\ l^2\ /\ 24\ P^2$ in which L is the standard

length of tape, g the weight per unit length of tape, l the unsupported length of tape or distance between points of support and P the pull used in measuring. The same system of units must be used in expressing g and P. The correction for sag is always subtracted from the standard length of tape.

Correction for Tension is obtained by the formula $L(P - P_1)/A\,E$ in which L is the standard length of tape, P the pull used in measuring, P_1 the pull at which the tape is standard, A the area of cross-section of the tape, E the modulus of elasticity of the material of which the tape is composed. The correction is added algebraically to the standard length of tape. By equating the formulas for corrections of sag and tension a value of P can be found which will counteract the effect of sag so that these two corrections can be neglected if this pull is used. This pull is called normal tension. In surveys of small areas, if the tape is standardized by supporting it in the same way and by applying the same pull as will be used in the field, corrections for sag and tension may be eliminated.

Correction for Slope will have to be applied where the base line is measured on a slope instead of on the horizontal. Let L be the measured length on the slope and h the difference in height between the two ends, the correction is $h^2/2\,L + h^4/8\,L^3$ and is to be subtracted from L. If the grade is under 3% the second term in the above formula may be neglected. On very steep grades it may be more convenient to find this correction in terms of the angle of the slope.

Length of Base at Sea Level is found by the formula Lh/R where L is the length of base, h the difference in height between sea level and the level of the base site, R the radius of the earth at the point in question. This correction is subtracted from L and need only be applied in extensive triangulation work where it is necessary to obtain perfect agreement in the sides of triangles computed from different bases.

The Most Probable Value of the measured base is the mean of the corrected measurements. The probable error or accuracy of the work can be found by the method of least squares. Accuracy of base measurements as great as 1 in 500 000 is sufficient to correspond with the accuracy of 1 in 150 000 in angular measures obtained in primary work. In secondary and tertiary work the accuracy of the base measurements may be reduced to correspond with an accuracy in angular measurements of 1 in 100 000 or 50 000 in the former case and 1 in 10 000 in the latter.

The Adjustment of the Triangulation System consists of a number of different steps. If any observations have been made either from or on positions not directly over a station, the observed angles have to be changed to what they would have been had the station been occupied. In extensive work, a small correction is applied to the angles so that their values would be the same if read at sea level. In large triangles the sum of the three angles will be more than 180° since the angles measured are spherical angles. See (4), (7), (10a), (24a) and (24b).

The Spherical Excess amounts to about 1″ for each 75 square miles of area of triangle. It may be computed from the following formula in which E is the spherical excess, b and c are the sides of the triangle in feet adjacent to angle A of the triangle and R is the mean radius of the earth in feet, the logarithm of which is 7.32068: $E = b\,c \sin A/2\,R^2 \sin 1''$. One third of this excess is subtracted from each angle so that the plane angles may be used for further calculations in determining the lengths of the sides.

Local or Station Adjustments are made at each station which depend upon the relation of the angles to each other at the station. If the angles are measured with a repeating instrument, two kinds of conditions are possible for a station adjustment: An angle can be formed from two or more others and the sum of the angles around the horizon should equal 360°. If the angles are measured with a direction instrument, a different method of forming the condition equations is followed.

General or Figure Adjustments depend upon the geometrical relations to form closed figures. The conditions of figure adjustments are the sum of the angles of each triangle must equal 180° and the length of any side as computed from the base should be the same whatever route is chosen thru the system. In extensive surveys such as are made by the U. S. Coast and Geodetic Survey, the most probable values of the angles and sides are found from the conditions imposed by the above adjustments by the method of least squares. The expense of such computations is not warranted in small surveys and sufficient accuracy is obtained by measuring the

angles of a triangle so that the sum of the angles is within 5″ of 180° and then distributing the error equally over the three angles so as to make the sum exactly 180°. Spherical excess can be disregarded since the triangles are not large enough to be considered as spherical triangles. By performing careful work in measuring the angles and the base line, the computations thruout the system can be made without further adjustments and the result be within the limit of accuracy consistent with city work or 1 in 40 000 to 50 000.

When the angles in the different triangles have been adjusted the lengths of all the sides in the system are computed, starting with a triangle in which the base line forms one of the sides. Since all three angles and one side of this triangle are known, the other sides can be readily computed by trigonometry. Each side computed in this manner forms a side of one of the adjacent triangles and this triangle is solved in a similar manner. The whole system is worked thru in this way until the lengths of all the sides have been computed.

The Geodetic Position of some of the points in the system should be found by observations for latitude and longitude. The azimuth of some of the sides should be obtained by observations on the meridian. From these observed positions the geodetic position and azimuth for any of the other points and sides can be determined by calculation. See (2), (3), (4), (7), (8), (10a), (18), (24a) and (24b).

Closed Traverses may be run from any of the points on the triangulation system to locate any of the topographical details desired. The accuracy of the methods employed will depend upon the work to be done. State boundaries, monuments defining property lines and important points of this character warrant an accurate location. The traverse in such a case should be run with a line joining two points in the triangulation system as one side of the traverse. The traverse can be closed on this line and its accuracy definitely calculated. Accuracy as high as 1 in 40 000 or better may be obtained if attention is given to the following points: Use transits reading to 20″ or 30″; be careful in centering over points and sight on plumb bob strings or pencils held over points; repeat the angles; use tape with standard pull and apply temperature corrections to measurements, measurements being made to the nearest hundredth of a foot. If an accuracy of one in 5 000 to 10 000 is desired, the angles need only be read to the nearest minute, and tapes read to the nearest tenth of a foot, temperature corrections and pull being neglected.

A Closed Traverse is Balanced by first finding the error of closure. In the case of traverse work laid out with transit and tape, it can be assumed that the error is due more to the measurements with the tape than to the angular measurements. The error is therefore distributed thruout the various sides forming the traverse so that only the lengths will be changed. The traverse is referenced to two coördinate axes at right angles to each other. One of the axes may be a meridian or a line in the traverse. The projection of any line in the traverse on the meridian axis is called its latitude; its projection on the other axis is called its departure. The rule for distributing the error of closure is as follows: The correction in latitude or departure of any course is to the total error in latitude or departure as the latitude or departure of the course is to the arithmetical sum of the latitudes or departures. See (4) and (14).

Rectangular Coördinate System. In extensive triangulation work a point in the system is located by its latitude and longitude. In surveys for cities the effect of the earth's curvature and hence the convergence of the meridians may be disregarded on account of the small area involved and it is much more convenient to locate the points with reference to two coördinate axes at right angles to each other. One of the axes chosen may coincide with a meridian line. Distances measured along the meridian

axis are known as ordinates or y distances and distances along the other axis as abscissas or x distances. In order that all x and y distances may be positive, it is convenient to locate the origin of the axes outside of the area of the survey or, if it falls within the area, to give it a distance from some arbitrary or zero origin so that the x and y distances will never be negative. Points are then referenced to the origin as so many feet north and east. With this system the location of any point is always definitely known since all surveys are tied to each other by being referred to the same reference lines. The coördinates of an unknown point can be calculated from those of a known point if the angle and distance from the known point to the unknown point are measured.

Permanent Monuments such as stone bounds or concrete posts with a drill hole in the top face to mark the center, are placed to mark all important points unless the point comes on some permanent structure not liable to be disturbed. Monuments are also placed to define the street lines in a city layout. The permanent monuments defining street lines are usually not set, if the construction of the street is going to disturb them, until the construction work is finished. Street monuments are set at the intersection of center lines of streets, at one side of the center, on one side of the street and sometimes on both sides. Monuments located within the carriageway are sure to be disturbed. It is better to locate them on the sidewalk at a certain distance out from the property line so that they will always be intervisible and accessible. When a monument is set, it is important to take offsets from it to permanent points on buildings nearby. If the reference points are well chosen they make a good check at any time to tell whether or not the monument has been disturbed. See (4), (7), (10a), (24a), (24b) and (27b).

TOPOGRAPHICAL SURVEYING

7. Stadia Measurements

The Stadia method is used for measuring distances by means of a graduated rod and the auxiliary wires in the transit telescope. It is a useful and economical method for locating points in any topographical survey. The azimuth, elevation and distance of any point may be obtained by this method from some known point. The two wires, one above and the other below the central horizontal cross-wire in the transit telescope are known as the stadia wires, the space between them usually being fixed. See (4) and (14).

Method of Using the Stadia. The transit is set up in the ordinary manner over some known point. A rod graduated to feet and hundredths is held vertically on the point whose location is desired. With the verniers properly set, the instrument is sighted on the rod and the horizontal circle read, which gives the azimuth of the point or its horizontal angle from some known line in the survey. One of the stadia wires is then brought in coincidence with an even foot mark on the rod and the intercept on the rod between the two stadia wires is read in feet and hundredths of a foot. If the telescope is so constructed that the ratio of the focal distance of the objective to the distance between the stadia wires is 100, an intercept of 1 ft on the rod means that the point at which the rod is held is 100 ft from the objective of the instrument when the telescope is horizontal. A 2-ft intercept would be 200 ft and so on. To obtain the distance to the center of the instrument, the focal distance of the objective and the distance

from the objective to the center of the horizontal axis should be added to the distance as calculated by the rod intercept. The focal distance of the telescope may be obtained by focusing the telescope on a distant point, such as a star, and measuring the distance from the center of the objective to the plane of the wires. The distance of the objective from the center of the horizontal axis may be measured directly on the telescope. The sum of these two distances may ordinarily be taken as 1 ft.

If the point to be located is at a different elevation from the point at which the transit is set, the vertical angle is read. To measure the vertical angle, the vertical distance from the point over which the instrument is set to the center of the horizontal axis of the telescope is measured by a tape or a rod. The center horizontal cross-wire is then set at this same distance on the rod which is held vertically on the point, the location of which is required. The vertical angle is obtained by reading the vertical circle. In such a case the horizontal distance as obtained from the rod intercept between the stadia wires will have to be corrected depending upon the degree of the vertical angle. For vertical angles under 3°, no correction is necessary, where distances are not required nearer than 1 ft. Corrections for horizontal distance and differences in elevation are usually found by means of tables, diagrams or stadia slide rule which have been developed from the mathematical formulas on which the theory of the stadia is based. Altho the ordinary level rod may be used, it is rather difficult to read the rod when long sights are made. For this reason special stadia rods are used on which the graduations are more plainly marked. When, due to obstructions, only one of the stadia wires on the rod can be seen, the rod intercept may be obtained by multiplying by two the intercept read between the visible stadia wire and the center horizontal wire.

The Stadia Reduction Tables which follow have been calculated on the basis of inclined distances of 100 ft and give the difference in elevations for vertical angles varying by 2′ from 0° to 20° and the horizontal corrections for distances of 100 to 1 000 ft for vertical angles from 0° to 20°.

Example. Suppose the observed vertical angle and the rod intercept were 6° 2′ and 5.06 respectively. If the vertical angle was zero, the horizontal distance would be 506 plus 1, the constant of the instrument, or 507 ft from the center of the instrument. The difference in elevation between the observed point and the point at which the transit is set is found by multiplying the value 10.45 corresponding to 6° 2′ by 5.07 which equals 52.98 ft. The horizontal distance is found by subtracting the horizontal correction as follows: 507 ft minus 5.5 ft equals 501.5 ft. The difference in elevation and the horizontal distance may be computed for angles larger than those given in the table by means of the formulas following.

$$\text{DIFFERENCE IN ELEVATION} = (d/i)\gamma \times \tfrac{1}{2} \sin 2a + (d + c) \sin a$$
$$\text{HORIZONTAL DISTANCE} = (d/i)\gamma \times \cos^2 a + (d + c) \cos a$$

d represents the focal distance of the objective, i the distance between stadia wires, γ the observed rod intercept between stadia wires, a the observed vertical angle, and c the distance on the telescope from center of objective to center of horizontal axis. In most transits d/i is 100 and $(d + c) = 1$ ft.

8. Plane-Table Surveys

The Plane-Table is a useful instrument for topographical work in that the survey is mapped in the field and the contours can be more accurately represented than if they were drawn in on the map at some later time from field notes. See (4) and (14).

Method of Work. A sheet of drawing paper is attached to the board, which is mounted on a tripod. The tripod and board are set over the

Table I.—Stadia Reduction Table (3)

Differences of Elevation

Min.	0°	1°	2°	3°	4°	5°	6°	7°	8°	9°
0...	0.00	1.74	3.49	5.23	[illegible]	8.68	10.40	12.10	13.78	15.45
2...	0.06	1.80	3.55	5.28	7.02	8.74	10.45	12.15	13.84	15.51
4...	0.12	1.86	[illegible]	5.34	7.07	[illegible]	10.51	12.21	13.89	15.56
6...	0.17	1.92	3.66	5.40	7.13	8.85	10.57	12.26	13.95	15.62
8...	0.23	1.98	3.72	5.46	7.19	8.91	10.62	12.32	14.01	15.67
10...	0.29	2.04	3.78	5.52	7.25	8.97	10.68	12.38	14.06	15.73
12.	0.35	2.09	3.84	5.57	7.30	9.03	10.74	12.43	14.12	15.78
14	0.41	2.15	3.90	[illegible].63	7.36	9.08	10.79	12.49	14.17	15.84
[illegible]...	0.47	2.21	3.95	5.69	7.42	9.14	10.85	12.55	14.23	15.89
18	0.52	2.27	4.01	5.75	7.48	9.20	10.91	12.60	14.28	15.95
20...	0.58	2.33	4.07	5.80	7.53	9.26	10.96	12.66	14.34	16.00
22...	0.64	2.38	4.13	5.86	7.59	9.31	11.02	12.72	14.40	16.06
24...	0.70	2.44	4.18	5.92	7.65	9.37	11.08	12.77	14.45	16.11
26...	0.76	2.50	4.24	5.98	7.71	9.43	11.13	12.83	14.51	16.17
28...	0.81	2.56	4.30	6.04	7.76	9.48	11.19	12.88	14.56	16.22
30...	0.87	2.62	4.36	6.09	7.82	9.54	11.25	12.94	14.62	16.28
32...	0.93	2.67	4.42	6.15	7.88	9.60	11.30	13.00	14.67	16.33
34...	0.99	2.73	4.48	6.21	7.94	9.65	11.36	13.05	14.73	16.39
36...	1.05	2.79	4.53	6.27	7.99	9.71	11.42	13.11	14.79	16.44
38	1.11	2.85	4.59	6.33	8.05	9.77	11.47	13.17	14.84	16.50
40...	1.16	2.91	4.65	6.38	8.11	9.83	11.53	13.22	14.90	16.55
42	1.22	2.97	4.71	6.44	8.17	9.88	11.59	13.28	14.95	16.61
44...	1.28	3.02	4.76	6.50	8.22	9.94	11.64	13.33	15.01	16.66
46...	1.34	3.08	4.82	6.56	8.28	10.00	11.70	13.39	15.06	16.72
48...	1.40	3.14	4.88	6.61	8.34	10.05	11.76	13.45	15.12	16.77
50...	1.45	3.20	4.94	6.67	8.40	10.11	11.81	13.50	15.17	16.83
52	1.51	3.26	4.99	6.73	8.45	10.17	11.87	13.56	15.23	16.88
54...	1.57	3.31	5.05	6.79	8.51	10.22	11.93	13.61	15.28	16.94
56...	1.63	3.37	5.11	6.84	8.57	10.28	11.98	13.67	15.34	16.99
58...	1.69	3.43	5.17	6.90	8.63	10.34	12.04	13.73	15.40	17.05
60...	1.74	3.49	5.23	6.96	8.68	10.40	12.10	13.78	15.45	17.10

Horizontal Corrections (3)

Distance	0°	1°	2°	3°	4°	5°	6°	7°	8°	9°
100..........	0.0	0.0	0.1	0.3	0.5	0.8	1.1	1.5	1.9	2.5
200..........	0.0	0.1	0.2	0.5	1.0	1.5	2.2	3.0	3.9	4.9
300..........	0.0	0.1	0.4	0.8	1.5	2.3	3.3	4.5	5.8	7.4
400..........	0.0	0.1	0.5	1.1	2.0	3.0	4.4	6.0	7.8	9.8
500..........	0.0	0.2	0.6	1.4	2.5	3.8	5.5	7.5	9.7	12.3
600..........	0.0	0.2	0.7	1.6	2.9	4.6	6.5	8.9	11.6	14.7
700..........	0.0	0.2	0.8	1.9	3.4	5.3	7.6	10.4	13.6	17.2
800..........	0.0	0.2	1.0	2.2	3.9	6.1	8.7	11.9	15.5	19.6
900..........	0.0	0.3	1.1	2.4	4.4	6.8	9.8	13.4	17.5	22.1
1000..........	0.0	0.3	1.2	2.7	4.9	7.6	10.9	14.9	19.4	24.5

point from which the observations are to be made and the board is leveled. A point on the paper is centered over the point on the ground by means of the plumb bob arm. Call this point *a*. Clamp the horizontal motion. The position of an unknown point *b* may now be determined by bringing the edge of the ruler of the alidade in coincidence with the plotted position of *a* at the same time sighting on a rod held at *b*. Draw a line along the edge of the ruler when in this position. By means of the stadia, calculate the

Table I.—Stadia Reduction Table (3)

Differences of Elevation

Min.	10°	11°	12°	13°	14°	15°	16°	17°	18°	19°
0......	17.10	18.73	20.34	21.92	23.47	25.00	26.50	27.96	29.39	30.78
2......	17.16	18.78	20.39	21.97	23.52	25.05	26.55	28.01	29.44	30.83
4......	17.21	18.84	20.44	22.02	23.58	25.10	26.59	28.06	29.48	30.87
6......	17.26	18.89	20.50	22.08	23.63	25.15	26.64	28.10	29.53	30.92
8......	17.32	18.95	20.55	22.13	23.68	25.20	26.69	28.15	29.58	30.97
10......	17.37	19.00	20.60	22.18	23.73	25.25	26.74	28.20	29.62	31.01
12......	17.43	19.06	20.66	22.23	23.78	25.30	26.79	28.25	29.67	31.06
14......	17.48	19.11	20.71	22.28	23.83	25.35	26.84	28.30	29.72	31.10
16......	17.54	19.16	20.76	22.34	23.88	25.40	26.89	28.34	29.76	31.15
18......	17.59	19.21	20.81	22.39	23.93	25.45	26.94	28.39	29.81	31.19
20......	17.65	19.27	20.87	22.44	23.99	25.50	26.99	28.44	29.86	31.24
22......	17.70	19.32	20.92	22.49	24.04	25.55	27.04	28.49	29.90	31.28
24......	17.76	19.38	20.97	22.54	24.09	25.60	27.09	28.54	29.95	31.33
26......	17.81	19.43	21.03	22.60	24.14	25.65	27.13	28.58	30.00	31.38
28......	17.86	19.48	21.08	22.65	24.19	25.70	27.18	28.63	30.04	31.42
30......	17.92	19.54	21.13	22.70	24.24	25.75	27.23	28.68	30.09	31.47
32......	17.97	19.59	21.18	22.75	24.29	25.80	27.28	28.73	30.14	31.51
34......	18.03	19.64	21.24	22.80	24.34	25.85	27.33	28.77	30.19	31.56
36......	18.08	19.70	21.29	22.85	24.39	25.90	27.38	28.82	30.23	31.60
38......	18.14	19.75	21.34	22.91	24.44	25.95	27.43	28.87	30.28	31.65
40......	18.19	19.80	21.39	22.96	24.49	26.00	27.48	28.92	30.32	31.69
42......	18.24	19.86	21.45	23.01	24.55	26.05	27.52	28.96	30.37	31.74
44......	18.30	19.91	21.50	23.06	24.60	26.10	27.57	29.01	30.41	31.78
46......	18.35	19.96	21.55	23.11	24.65	26.15	27.62	29.06	30.46	31.83
48......	18.41	20.02	21.60	23.16	24.70	26.20	27.67	29.11	30.51	31.87
50......	18.46	20.07	21.66	23.22	24.75	26.25	27.72	29.15	30.55	31.92
52......	18.51	20.12	21.71	23.27	24.80	26.30	27.77	29.20	30.60	31.96
54......	18.57	20.18	21.76	23.32	24.85	26.35	27.81	29.25	30.65	32.01
56......	18.62	20.23	21.81	23.37	24.90	26.40	27.86	29.30	30.69	32.05
58......	18.68	20.28	21.87	23.42	24.95	26.45	27.91	29.34	30.74	32.09
60......	18.73	20.34	21.92	23.47	25.00	26.50	27.96	29.39	30.78	32.14

Horizontal Corrections (3)

Dist.	10°	11°	12°	13°	14°	15°	16°	17°	18°	19°
100.....	3.0	3.6	4.3	5.1	5.9	6.7	7.6	8.5	9.5	10.6
200.....	6.0	7.3	8.6	10.1	11.7	13.4	15.2	17.1	19.1	21.2
300.....	9.1	10.9	13.0	15.2	17.6	20.1	22.8	25.6	28.6	31.8
400.....	12.1	14.6	17.3	20.2	23.4	26.8	30.4	34.2	38.2	42.4
500.....	15.1	18.2	21.6	25.3	29.3	33.5	38.0	42.7	47.7	53.0
600.....	18.1	21.8	25.9	30.4	35.1	40.2	45.6	51.3	57.3	63.6
700.....	21.1	25.5	30.2	35.4	41.0	46.9	53.2	59.8	66.8	74.2
800.....	24.2	29.1	34.6	40.5	46.8	53.6	60.8	68.4	76.4	84.8
900.....	27.2	32.8	38.9	45.5	52.7	60.3	68.4	76.9	85.9	95.4
1000.....	30.2	36.4	43.2	50.6	58.5	67.0	76.0	85.5	95.5	106.0

horizontal distance and difference of elevation between *a* and *b*. The point *b* is plotted by scaling off this distance on the line drawn on the paper. Its elevation is noted opposite its plotted position. Other points may be located and plotted in the same manner. The contours and other topographical detail taken at one set up may be drawn in on the sheet as the survey is made. In a similar manner, the whole area to be surveyed may be plotted in the field by observations from different points. The

different drawings can then be combined into one map of the size desired. It is not practicable to work with the plane-table except in pleasant weather. This instrument is extensively used in the topographical work carried out by the United States Government.

Traverses may be run with the plane-table as follows: In Fig. 10, the plane-table is set over *a*, and *b* is located by the method previously described.

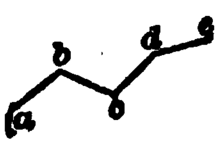

Fig. 10

Take the table to *b* and set the plotted position of *b* over point *b* on the ground with the horizontal motion of the table unclamped. Place the edge of the ruler or alidade coincident with the plotted line *a b* and sight back on point *a* and clamp the table. Now locate and plot point *c* from *b*. Move the table to *c*, orient on *b* and then locate *d*. In a similar manner other points of the traverse are located and plotted, care being taken to orient the table at each set up.

Intersection Method of Location is as follows: In Fig. 11, the points *a*, *b*, *c*, *d* and *e* are to be located. Set the table over *a* and make pointings at *b*, *c*, *d* and *e*, each time drawing the lines on the board showing the direction of these points from *a*. Take the distance of *b* from *a* by stadia or direct measurement and plot *b* on the line *ab*. No other distances need be measured. Move the table to *b*, set the plotted position of *b* over point *b* on the ground and orient table on *a*. Point the alidade and draw lines to *c*, *d* and *e*. The intersections of these lines with the lines drawn to these respective points when the table was at *a* locate the points *c*, *d* and *e*.

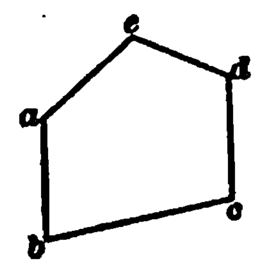

Fig. 11

The Resection Method of Location is used to locate a point from a base line as in the intersection method, except it is impossible to set the instrument over but one end of the base line *a b*. In Fig. 11 it is desired to locate *c* from the base *a b*. Set the table over *a*, point to *b*, measure *a b* and plot *b*. Point to *c* and draw indefinite line *a c*. Assume that *a c* is not measured, but that its distance may be approximated. Plot the approximate position of *c* on line *a c*. Move the table to *c*, setting the plotted position of *c* over *c* on the ground. Orient the table on *a*. With the edge of the ruler of the alidade coincident with plotted position of *b* sight on *b* and draw a line which will intersect the line *a c* and give the correct position of *c*. The new position of *c* should then be set over the point *c* on the ground and the table oriented on *a* or *b*, after which the table is in position to continue the work.

The Three Point Problem consists in finding the plotted position of a point from observations on three points already plotted on the sheet. In Fig. 11, the position of points *e*, *d* and *c* have been plotted. It is desired to set the table over the point *b* on the ground and orient it so as to continue the work. Place a sheet of tracing cloth over the drawing and set the table over *b* on the ground, choosing any convenient point on the tracing cloth as the plotted position of *b*. With the alidade coincident with this position of *b* make pointings and draw indefinite lines on the tracing cloth to the field positions of *e*, *d* and *c*. Remove the alidade and shift tracing cloth until the three lines on the cloth pass thru the plotted positions of *e*, *d* and *c*. Prick thru the intersection of these three lines to the paper and this point will be the plotted position of point *b*. Set up table with this plotted position of *b* over *b* on the ground, orient on *e*, *d* or *c* and proceed with the work.

ASTRONOMICAL OBSERVATIONS

9. Astronomical Terms

The geodetic or geographical position of a point on the earth's surface is completely described by its latitude and longitude. For methods of determination of latitude and longitude, see (2), (3), (4), (7), (8), (10a) and

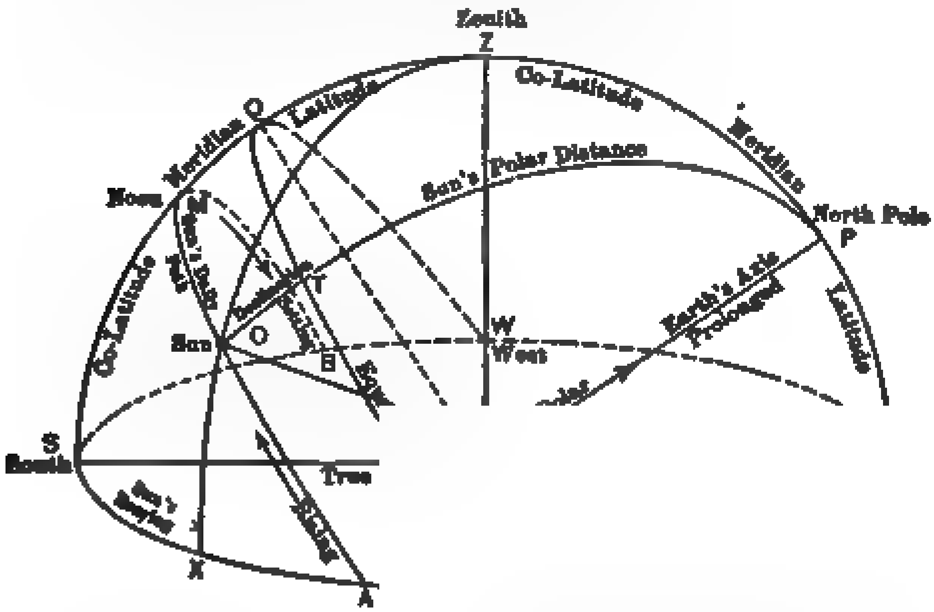

Fig. 12. Celestial Sphere (3)

(18). It is frequently necessary in higway surveys to find the azimuth of one or more of the lines of the survey. The following definitions of astronomical terms are given in order to make clear the methods of determining the asimuth (see Fig. 12).

The Celestial Sphere is a sphere having the earth as a center and a surface of infinite radius.

The Polar Axis is the earth's axis produced.

The Horizon is the great circle *S E N*.

The Zenith *Z* is the point on the celestial sphere on a vertical thru the observer's position and perpendicular to the plane of the horizon.

The Meridian *S Z N* is the line of intersection of a plane, passing thru the zenith and the poles, with the celestial sphere.

The Declination *O T* of a body is the angular distance north or south of the equator measured on a great circle passing thru the pole and the body, perpendicular to the equator. The declination is positive when north of the equator and negative when south of the equator.

The Polar Distance *O P* of a body is the distance of a body from the pole measured on a great circle. It is always equal to 90° minus the declination. When the declination is negative, the polar distance will hence be greater than 90°.

A Vertical Circle *Z O* is the line of intersection of a plane, with the celestial sphere, which passes thru the zenith and the body and is perpendicular to the horizon.

Altitude *O X* is the distance of the body above the horizon measured on a vertical circle.

The Zenith Distance ZO is 90° minus the altitude.

Azimuth is the angle QZO at the zenith between the meridian and a vertical circle thru the body, or the arc on the horizon between the meridian and the point where the vertical circle thru the body, intersects the horizon.

Longitude is the arc measured on the equator between the meridian passing thru the point of the observer and some other meridian. All longitudes are usually referred to the Greenwich meridian.

Latitude QZ of a point is the distance of its zenith above the equator, measured on the meridian.

Refraction is the displacement of the rays of light from a celestial body due to atmospheric conditions. All bodies hence appear higher than they really are and the observed altitudes have to be changed by subtracting a correction for refraction. Refraction corrections may be found from Bessel's Refraction Tables. See also (2), (3), (4), (7), (8), (10a) and (18).

The American Ephemeris and Nautical Almanac is published by the U. S. Government and contains data relative to the position of many of the celestial bodies with reference to the Greenwich meridian. The declination of the sun is tabulated for each day at Greenwich noon together with the rate of hourly change. For positions at any other meridian than Greenwich and at any other instant than noon, the difference in time must be found between the time of the observation at the observer's meridian and the Greenwich meridian. The rate of hourly change is applied to this interval of time and the value of the declination is interpolated from the value given in the table.

10. Determination of Azimuth

Azimuth is usually measured continuously from 0 to 360° from the south point by the way of west, north, and east. It is hence necessary to determine the position of the true meridian before the azimuth can be found. Approximate values of the azimuth may be found with the compass, Accurate determinations can be made by observations with a transit on the stars or sun. See (4), (7), (8), (10a), (24a) and (24b).

By Compass. Angles read direct from the compass give the magnetic bearing of the line since the needle points to the magnetic meridian. The needle points to the true north or meridian at only a very few places. The angle between the plane of the true meridian and the magnetic meridian is called the magnetic declination of the needle. The declination is described as east or west respectively, as the needle points east or west of the true meridian. The magnetic declination is subject to several variations as follows: Secular, daily, annual and irregular variations. Secular variation is the most important. The annual variation can be neglected. The total movement of the daily variation is from 5′ to 15′ of arc. Irregular variations are those due to magnetic storms. The amount of declination for any place may be approximated by empirical formulas or from the isogonic charts prepared by the U. S. Coast and Geodetic Survey. On the isogonic chart, places having the same magnetic declination are connected by lines called isogonic lines. An accurate determination of the declination can be made with the compass by finding the true meridian by observation on Polaris. The bearing of the true meridian is the amount of the declination. By drawing a figure of the north, south, east and west lines, it is readily seen whether the observed declination is to be added to or subtracted from the magnetic bearing to get the true bearing. The azimuth

of a line referred to the south point is calculated from its true bearing as follows: If its bearing is southwest, the azimuth and bearing are the same; if northwest, add 90° to get the azimuth; if northeast, add 180°; if southwest, add 270°.

By Observation on a Star. A simple method is to observe Polaris at either its eastern or western elongation. Polaris is a convenient star to use because it is readily found in the heavens due to its magnitude and its position with reference to the constellation Cassiopeia and the Great Dipper, Ursa Major, see Fig. 13. A line thru the two stars in the outer edge of the Dipper always points approximately to the pole star, which can be distinguished on account of its brightness or magnitude. The star is in upper or lower culmination when vertically above or below the pole respectively and in eastern or western elongation when east or west of the pole. The transit is carefully set up over a point on the ground and the telescope pointed at the pole star. The vertical cross-wire is kept on the star until its motion in an easterly or westerly direction ceases. The telescope is then depressed and a point set at some distance away on the ground. The interval of elongation is sufficiently long so that the operation can be repeated several times and an accurate location of the point on the ground secured. The angle between the true meridian and the pole star at elongation may be calculated by the formula $\sin a = \sin p \sec l$ in which a is the angle required, p the polar distance of the star, and l the latitude of the observer. This angle is turned off in the proper direction from the line established on the ground, thus defining the line which will be a true north and south line. If the point, over which the transit is set up, is a point in some line of the survey, the azimuth of this line can then be measured by finding the angle between it and the meridian. The azimuth of the other lines in the survey can be calculated with reference to this line by means of the horizontal angles.

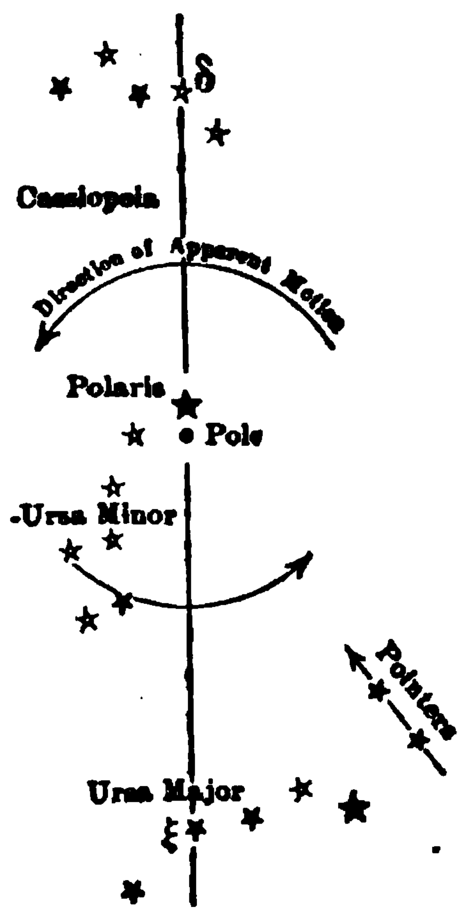

Fig. 13

By Observation on the Sun with Engineer's Transit. See (2), (3), (4), (7), (8), (10a) and (18).

By Observation on the Sun with Solar Attachment. By means of the solar attachment the meridian line is determined directly by observation without any calculation. The method with a Saegmuller solar attachment will be described. Set up the transit with its solar attachment over a point on the line whose azimuth is to be determined. Sight at a distant point in this line with the verniers set at zero and clamp the lower motion. Bring the solar telescope into the same vertical plane as the line of sight of the transit by sighting on the same point. Make the telescope of the transit level by means of its attached level. Calculate the declination of the sun from the Ephemeris for the time the observation is to be made. It will be necessary to correct the declination for refraction. Point the transit telescope approximately south by means of the compass and clamp the plates. Set the vertical angle equal to the sun's corrected declination, pointing the transit telescope upward if declination is south and downward if

north declination. Next make the solar telescope level by means of its level bubble and clamp it. Then point the telescope of the transit upward with a vertical angle equal to 90° minus the latitude. This brings the polar axis of the solar telescope parallel to the polar axis of the earth. The relative positions of the transit and solar attachment are shown in Fig. 12. Next point the solar telescope at the sun, bringing the sun's image to the center of the square by the four cross-wires in the solar telescope and clamp. Make an accurate pointing by means of the tangent screw on the horizontal plate of the transit and the tangent screw of the polar axis of the solar attachment. The line of sight of the transit now lies in the plane of the meridian since the vertical axis points to the zenith, the polar axis to the pole and the solar telescope to the sun. The angle between the meridian and the reference line is read on the horizontal plate of the transit. Observations should not be made near noon, sunrise or sunset as the best results are not obtained during these periods.

HIGHWAY SURVEYING

11. Scope of Highway Surveying

Surveys for Streets. The importance of property values within the city limits demands that the work of the survey be done with extreme accuracy in order to avoid extensive and troublesome litigation. The endless trouble ensuing from existing old surveys, which have been made from time to time as the city has grown, as well as the addition of suburban areas has been the cause of resurveying many of the larger and more important cities. The plan usually followed is to establish a system of triangulation or of closed traverses. From points on these systems other traverses are run out so that ultimately all monuments, street lines, etc, are referenced in with the main system and accurately located. For purposes of drawing up a plan of the street system in undeveloped areas or improving the present street plan, a survey of this kind should embrace taking all the topographical details and contours, so that a comprehensive map of the area can be prepared. Surveys for the improvement of individual streets are made with reference to the monuments and should include all the information from which a plan, profile and cross-sections can be prepared.

Surveys for Roads. The nature of the work does not demand the same degree of accuracy as is required in city surveying. The surveys are not always tied in with any system of points previously established by triangulation or by closed traverses accurately balanced. A survey on one road may be made entirely independent of that on another road since the roads are usually so widely separated that there is no important relation between the two. Adjoining surveys on the same road should be connected with each other but even then it is not essential that the stationing be continuous. In those states which have been divided into townships and sections by north and south lines run according to the true meridian and other lines crossing them at right angles in the same manner that the Public Land Surveys of the United States are made, monuments will be found marking the township and section corners. By referencing the road survey to these monuments, an accurate check on the work can be obtained. The information obtained for the improvement of an individual road should be such that a plan, profile and cross-sections can be prepared. Much of the data mentioned in Sect. 4 can be obtained at the time the survey is made, such as conditions of foundation and drainage, shipping points, locations of

material which is available for construction purposes, and examination of culverts, bridges and other structures.

Surveys for Maps. Topographical maps of several of the states prepared by the U. S. Geol. Survey may be obtained, but it frequently happens that, where a system of roads is contemplated, no road map of the area is available. A plan map showing roads, water courses, county and town lines is sometimes all that is desired. Such a map may be prepared with sufficient accuracy from the surveys of the roads, as they are made, if these surveys are connected and balanced as closed traverses. Extensive surveys have been made in some states, covering the whole system of highways within the state, for the sole purpose of making a road plan.

12. Selection of Location

Factors Which Should Be Considered in making a selection of location are discussed in Sects. 4, 6 and 7. The problem is often very much simplified due to the fact that the proposed improvement follows an existing highway and many of the features which would influence the location can be seen by traveling over the highway. Where there is some doubt as to the best location, a reconnaissance of the area should be made and one or more preliminary surveys run until the best route is found. If comprehensive topographical maps are obtainable, map locations of the proposed highway may be made, in which case the necessity for more than one survey in the field may be avoided.

13. Transit Line

Surveys for individual streets or roads are made with reference to a transit line. In the case of city streets the transit line would be tied in with the monuments found along the streets that have previously been located from the triangulation or traverse system. In the western states the transit line is generally tied in with the monuments designating township and section corners that have been established by the U. S. Public Land Survey. As a general rule the transit line should be run so as to coincide with the center line of the proposed location. Information for locations which follow the old right-of-way, however, may be just as accurately obtained from a line run at one side of the highway as one run on the proposed center line. Traffic conditions often interfere with running the transit line in the center of the highway. In some cases where a car track is located in the road, the transit line may be made to coincide with the line of one of the rails, in which case the relocation of the line at any later time is an easy matter without the use of a transit. When the transit line does not coincide with the finished center line, the offsets to the finished center line may be obtained from the plan location of the latter. These offsets, when used in connection with the transit line in the field, will serve to locate the finished center line of road for construction purposes.

1. **Mich. State Highway Comm. Method (26b).** "In establishing center line, permanent monuments of U. S. Government land surveys are followed. If such monuments do not exist, section and quarter-section corners must be established following the methods of the U. S. Government survey. The plan must contain a description in sufficient detail so that the road can be plotted on township maps, referring to U. S. Government survey points and give exact location of points of beginning and termination. In the case of angling roads, where the center line crosses section or quarter-section lines, the station or place at the intersection must be noted together with the distance to the nearest section or quarter-section monument. All angles must be

marked with permanent monuments set on the center line. The plan should have upon it a small key map of the township showing the location of the road."

Survey Party and Its Equipment. The party for road surveys usually comprises one transitman and three assistants who serve as rodmen and chainmen. The equipment should include the following instruments: one engineer's transit reading to 1′ or 30″, one 100-ft steel tape graduated to feet and hundredths of a foot, two 50-ft metallic tapes, one self-reading level rod, range poles, pins, plumb-bobs, spikes, tacks, chalk, axe, sledge, stakes and some red cloth.

N. Y. State Highway Comm. Practice (12). "The survey party will usually consist of the following: One surveyor in charge; 1 instrument man; rodmen, chainmen, axemen, to the number of 5; making a total of 7 in the party. The equipment shall include a transit and a level, 2 steel chain tapes 100 ft long, 2 sighting poles, 3 plumb-bobs, 2 level rods, 3 50-ft metallic box-tapes, 2 hatchets, crayon, pencils, scales, note book covers and sheets, copy of official general instructions, blanks for reports, expense accounts, vouchers, hotel bills, etc. Nails, spikes, cloth, and such articles should be bought in the field. All useful data of previous surveys in the vicinity shall be carried; these shall include B.M.'s, transit point ties, and a diagram of base-lines showing station equalizations; these must be copied before going into the field, so that the original notes will not be removed from the office.

"A small camera will be furnished each survey party, and photographs shall be taken of any bridge, culvert, retaining wall or other object or place, the treatment of which in preparing plans will, in the judgment of the engineer in charge, be a matter requiring extra precaution or study. It is not desired that photographs be taken of any objects or places, the proper treatment of which presents no unusual features. All films must be carefully listed, and the prints, when made, must be incorporated in the note book near the proper station; when the survey base line is in the field of view it should be indicated on the picture. Films sent to the First Deputy's office will be developed and printed there."

The Transit Line is Stationed every 50 or 100 ft depending upon the character of the topography and the accuracy desired for the estimate of grading. Surveys for highway work require the measurement of the actual distances around the arc where curves occur. Stationing, however, may be measured along the tangents of a curve without appreciable difference from the actual curve length when the external angle between the tangents is less than 10°.

Running the Line. The chief of party first plans out the location of the tangents and intersection points. Spikes pushed thru a piece of red cloth are convenient for marking the intersection points temporarily as they may be driven so as not to be disturbed by the traffic and the piece of red cloth serves as a ready finder. Set the transit up over an intersection point and measure the angle between the tangents turning it off at least twice. Read and record the magnetic bearings of the two tangents as a check on the angle. The internal or external angle between the tangents may be measured, the external or intersection angle being preferable as it is more convenient to read, and is also used for figuring the curves and in mapping the survey. The external or other data necessary for computing the curve is measured and the curve to fit conditions is computed as shown in Art. 14. The tangent distances of the curve are laid off on the tangents each way from the intersection establishing the P. C. and the P. T of the curve. Starting from the initial point of the survey, the station intervals 50 or 100 ft apart are marked off on the tangent up to the P. C. of the curve. The curve can be run in between the two tangents by any one of the methods given in Art. 15. As the exact length of arc is used in the stationing, this distance is computed and added to the station of the P. C. which gives the station of the P. T. Measurements are continued along the next

tangent from the P. T. until the next P. C. is reached where the above operations are repeated. The points defining the 50 or 100-ft station intervals may be designated by some temporary mark on the transit line or by stakes or marks at the sides (see Art. 18). Measurements along the tangents should be made to the nearest hundredth of a foot in city work, while in work outside of the cities, the nearest tenth of a foot is sufficiently close to read the tape. Make all measurements with the tape horizontal. In cases where the transit line is not run coincident with the proposed center line, care should be taken to obtain curve data with reference to the proposed center line so as to get the correct stationing of the line. Points at the intersections of the tangents should be carefully tied in to objects that are permanent and readily accessible so that they may be reestablished at any time. Three tie distances are sufficient. Sketches showing references and ties should be shown in the field notes.

Taking Topography. The topography includes the shape of the ground and the location of all objects such as houses, walls, fences, gutters, curbs, culverts, bridges, water courses, catch basins, trees, monuments, edges of travelled way, ledge outcrops, poles, ditches, substructures and, in fact, any object that occurs within the limits of the survey that would be of importance in designing the highway. In connection with this work the names of the abutting property owners should also be obtained. Methods of taking topography which defines the shape of the ground are given in Art. 17. All topography is located with reference to the tangents of the transit line. A rapid method, which can be used except where a more accurate location is desired, is that of perpendicular offsets. This method also makes the plotting much easier. The offset is the perpendicular distance to the point measured from a station on the transit line opposite the point to be located. The perpendicular direction is estimated by eye with sufficient accuracy if the object is at not too great a distance. The offset distance and station of the line locate the point. The offsets and plus stations on the transit line may be measured with the metallic tape to the nearest tenth of a foot and in cases where the object is not well defined, the nearest foot will suffice. In locating fences, walls, curbs and similar objects, offsets need be taken only opposite stations at which they begin and end and at such intermediate points as will define their alignment. Measurements are made to the face of the wall or similar object and to the center of bounds. The method of perpendicular offsets may be used where curves occur provided the offsets are taken from the tangents between the P. I. and the P. C. and P. T. Lines which intersect the transit line at an angle are located by noting the station on the transit line at which the line in question, if prolonged, would intersect it, together with the perpendicular offset from a station on the transit line opposite some known point of the diagonal line. Stadia methods may be used to advantage if objects are some distance away or if much contour work is being done. The plane table is also applicable to this work if the survey is extensive as to width or in projecting preliminary lines thru new locations.

More accurate location of objects is required in city work and in the important parts of settled communities than would be obtained alone by the offset method. Points on the objects should be located by angles and distances, by intersection measurements taken from two definitely located points and combinations of these methods with the offset method. Measurements are made with the steel tape and read to the nearest hundredth of a foot.

The shape of the ground is obtained by cross-section levels or by contours. For a description of the methods, see Art. 17.

N. Y. State Highway Comm. Practice (12). "Every structure tributary to the highway must be located. However, no more time should be spent in locating objects beyond the probable limits of the improved highway than is necessary to ascertain their approximate size and location. All survey measurements must be sufficiently accurate for the preparation of the ordinary land-taking maps and deeds. The offsets to the existing fences, and all other measurements to objects within the highway, shall be taken to the nearest tenth of a foot. Similarly all permanent objects within 100 ft of the base line or farther if the proposed improvement will affect them, shall be located to the nearest whole foot. The location of all objects farther away may be estimated by eye; estimates should be so designated in the notes.

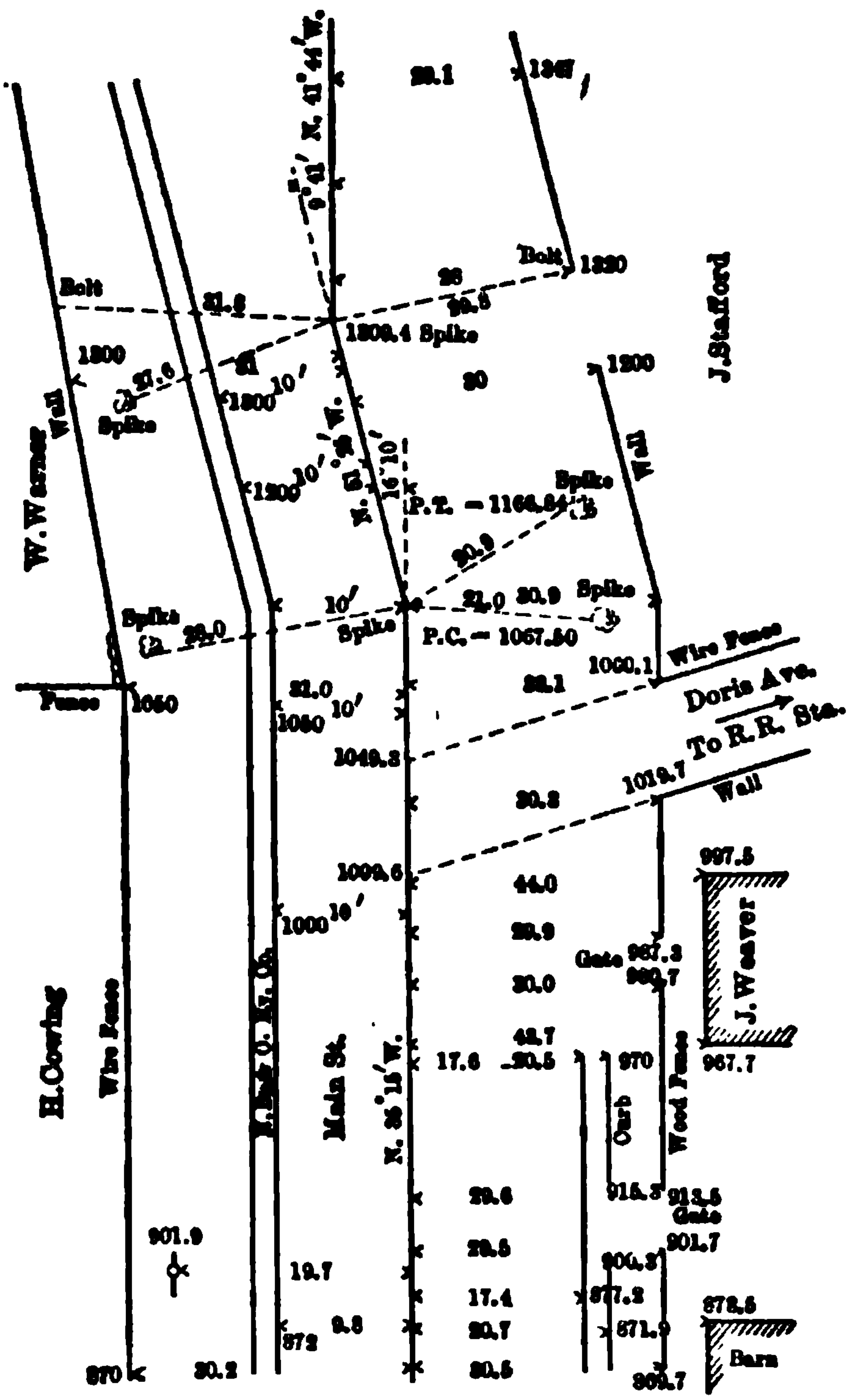

Fig. 14. Transit Notes

"The residences and other properties shall be roughly classified, and the approximate values of each class recorded, and the class designation of each stated in the notes. Special mention shall be made of any structure whose value is noticeably greater than the average value of those of its kind on the road.

"In general, walls, fences and other ordinary objects may be located by plus station and offset; offsets must be taken to every angle point of the highway boundary; when these points are farther apart than 300 ft, sufficient additional ones shall be taken to furnish total offsets not more than 300 ft apart. Lines separating the lands of abutters, except in thickly settled places and on extremely wide highways, and boundary lines of counties, towns, cities, villages and intersecting highways, must be located by magnetic bearing and base line intersection, and eye location is sufficient for the intersection point; and the station of the intersection, the azimuth of the intersecting line, and the distance along this line from the base line to the boundary line of highway, must be recorded. Any fence, wall, etc, not of the class mentioned above, may be located by the station of the intersection of its axis with the base line and the station and offset of its intersection with the highway boundary line.

"The name of each property owner must be recorded in its exact legal form, that it may without modification be used in deeds and other legal papers. At least two residents must be consulted as to the ownership of each property. Where a land taking will probably be made, the owner should be consulted on the subject if possible.

"The name of each highway in the survey, and of each connecting way, are to be

recorded; this requirement is to apply to work in villages and cities as well as in open country."

Two Methods of Recording Field Notes are shown in Figs. 14 and 15.

Fig. 15. Transit Notes

In the form shown in Fig. 15, the location of the topographical details would be recorded on the right-hand page.

14. Curve Formulas

Definitions. In Fig. 16, P. C. is the point of curve or beginning of the curve; P. T. the point of tangent or end of curve; P. I. the point of intersection or the point of intersection of the tangents produced; the intersection angle I, the external angle between the tangents and equals the angle at the center; R, the radius of curve; E, the external or distance between the P. I. and curve on a radial line produced; T, the tangent distance or the distance from the P. C. or P. T. measured along the tangent to the P. I.; M, the midordinate or the perpendicular distance from the long chord at its mid point to the curve; C, the chord joining the P. C. and P. T. Practically all curves in highway surveys are simple curves or combinations thereof, a simple curve being the arc of a circle. Parabolic curves are, however, sometimes employed instead of circular curves. Two simple curves of different radii having a common point of tangency, both curves being on the same side of the tangent, constitute a compound curve (see Fig. 17). P. C. C. is the point of compound curve. Two simple curves of the same or different radii on opposite sides of a common tangent constitute a reversed curve. P. R. C. is the point of reversed curve (see Fig. 18).

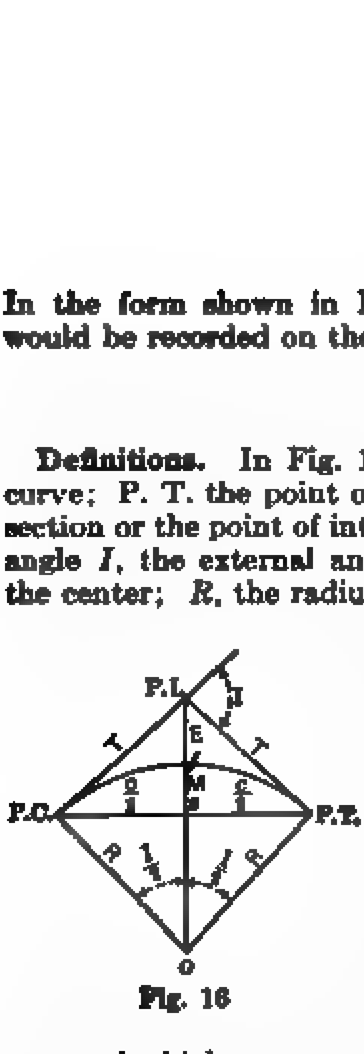

Fig. 16

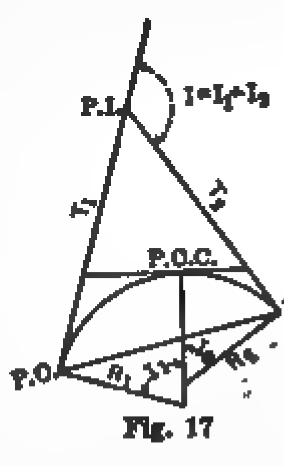

Fig. 17

NOTE: Curve tables IV, V, VI and VII are included in Art. 16.

The Degree of Curve D is the angle at the center subtended by an arc length of 100 ft. Thus in Fig. 19, if the arc length $a\,b$ is 100 ft, the angle D is the degree of curve. If the angle is 1°, the curve is known as a 1° curve, if 2°, a 2° curve and so on. If D is 1° and R the radius of the curve, and the arc length $a\,b$ is 100 ft, $D/360 = 100/2\pi R$ or $R = 360 \times 100/2\pi = 5729.58$ where $\pi = 3.1416$. In a similar manner for a 2° curve $R = 360 \times 100/2 \times 2\pi$. The radius for any degree of curve may be obtained by dividing the value R for a 1° curve by the degree of curve whose radius is desired. Since other functions of the curve are dependent upon the radius, they too may be found by dividing the corresponding values of a 1° curve by the degree of curve in question.

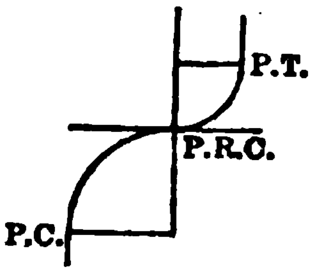

Fig. 18

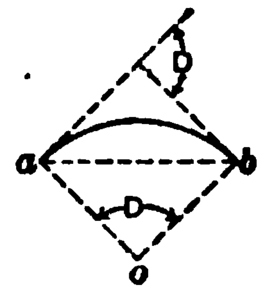

Fig. 19

The Actual Length of Arc may be found by Tables III and VII or by the formula

$$L = 2\pi R \times I/360 \qquad (1)$$

in which L represents the length of arc and other letters have the same significance as before. When the degree of curve is known

$$L = (I/D)\,100 \qquad (2)$$

In staking out curves by the ordinary method of deflection angles from the tangent, lineal measurements are made along the chords subtending the arc instead of the arc itself. In Table II is shown the difference between actual length of arc and measurements around chords of varying lengths for 5°, 15° and 30° curves. From the table it is seen that very close agreement is obtained if 100-ft chords are used for 0° to 5° curves, 50-ft chords for 5° to 15° curves, 25-ft chords for 15° to 30° curves and 10-ft chords for curves above 30°.

Table II.—Comparison of Arc Length and Subtended Chord

Degree of Curve	5°	15°	30°
Arc Subtended	Arc Lengths		
1–100 ft chord	100.04	100.29	101.15
2– 50 ft chord	100.01	100.07	100.80
4– 25 ft chord	100.01	100.02	100.07
10– 10 ft chord	100.00	100.00	100.01

Table III.—Multipliers for Finding Lengths of Circular Arcs (10 b)

	Degrees	Minutes	Seconds	
1	0.017453293	0.000290888	0.000004848	Example.
2	0.034906585	0.000581776	0.000009696	Find length of arc for a central
3	0.052359878	0.000872665	0.000014544	angle of 48° 45′ in circle of 12 ft radius.
4	0.069813170	0.001163553	0.000019393	40° 0.698132
5	0.087266463	0.001454441	0.000024241	8° 0.139626
6	0.104719755	0.001745329	0.000029089	40′ 0.011636
				5′ 0.001454
7	0.122173048	0.002036217	0.000033937	0.85085
8	0.139626340	0.002327106	0.000038785	12
9	0.157079633	0.002617994	0.000043633	Length = 10.210 ft.

Formulas for Simple Curves. In Fig. 20 $a\,g = g\,b = T$, the tangent distance, $g\,f = E$, the external, $f\,h = M$, the midordinate, $a\,b = C$, the long chord, $a\,o = R$, the radius, $q\,g\,b = a\,o\,b = I$, the intersection angle, D = degree of curve. The following equations may be derived by a solution of the triangles.

$$g\,a\,b = g\,b\,a = \tfrac{1}{2} I$$

$$a\,o\,h = h\,o\,b = \tfrac{1}{2} I$$

$$T = R \tan \tfrac{1}{2} I \tag{3}$$

T may be found also from Table IV.

$$E = R\,(\sec \tfrac{1}{2} I - 1) \tag{4}$$

$$E = T \tan \tfrac{1}{4} I \tag{5}$$

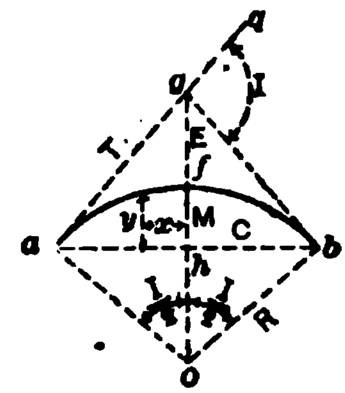

Fig. 20

E may be found also from Tables IV and VII.

$$M = R - \sqrt{R^2 - \tfrac{1}{4} C^2} \tag{6}$$

also

$$M = R\,(1 - \cos \tfrac{1}{2} I) \tag{6A}$$

Any perpendicular y to the chord a distance x from the midordinate is found by

$$y = \sqrt{R^2 - x^2} - \sqrt{R^2 - \tfrac{1}{4} C^2} \tag{7}$$

$$C = 2\,R \sin \tfrac{1}{2} I \tag{8}$$

$$R = T \cot \tfrac{1}{2} I \tag{9}$$

R may also be found by Table VII and when D is known by Table VI.

When $I = D$ then $R = \tfrac{1}{2} C/\sin \tfrac{1}{2} D$ (10)

When $a\,b = 100$ $R = 50/\sin \tfrac{1}{2} D$ (11)

When $a\,b = 50$ $R = 25/\sin \tfrac{1}{4} D$ (12)

When $a\,b = 25$ $R = 12.5/\text{sin.}\ \tfrac{1}{8} D$ (13)

When $a\,b = 10$ $R = 5/\sin D/20$ (14)

Formulas (11), (12), (13) and (14) were employed in computing values for the radii in Table VI. Up to $D = 7°$, (11) was used, 7° to 14°, (12) was used, 14° to 30°, (13) was used, and above 30°, (14) was used.

$$\text{When } I = D \text{ then } \sin \tfrac{1}{2} D = C/2\,R \tag{15}$$

D may also be found by computing R and finding corresponding value of D in Table VI. Table IV may also be used in finding D. See (11) and (15).

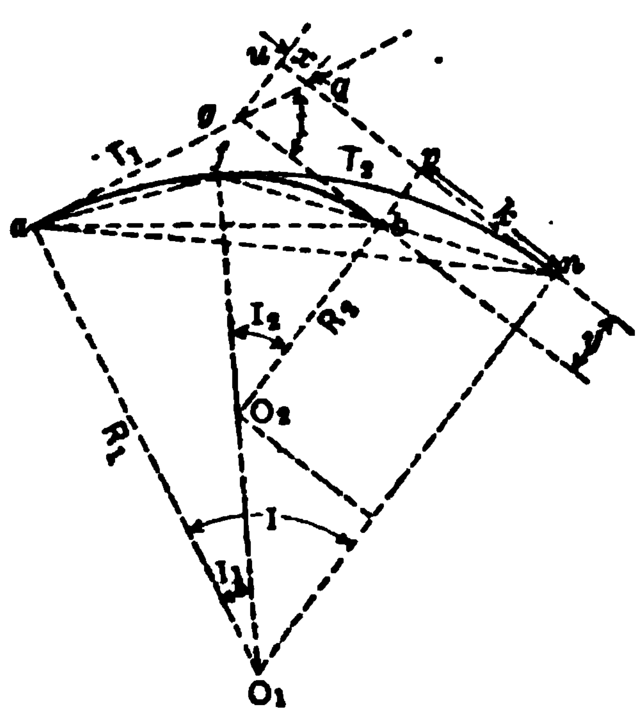

Fig. 21

Formulas for Compound Curves. In Fig. 21 the P. C. C. of the two curves $a\,f$ and $f\,b$ is at f

$$g\,a\,b + g\,b\,a = I$$

$$I = I_1 + I_2$$

Produce curve $a\,f$ to n so that the tangent $u\,n$ will be parallel to $g\,b$. Join f and n by a straight line, the line will pass thru b. Join o_1 and n. Draw $g\,u$ parallel to $o_2\,v$.

Given T_1, T_2, I and R_1 to find R_2,

$$x = q\,u = (R_1 \tan \tfrac{1}{2} I - T_1) \cos I$$

$$y = b\,v = g\,u = (R_1 \tan \tfrac{1}{2} I - T_1) \sin I$$

$$k = v\,n = R_1 \tan \tfrac{1}{2} I + x - T_2$$

$$\tan \tfrac{1}{2} I_2 = y/k$$

$$R_2 = R_1 - \frac{k}{\sin I_2} \tag{16}$$

Given $a\,b$, angles $g\,a\,b$ and $g\,b\,a$, and R_1 to find R_2,

T_1 and T_2 can be computed from triangle $g\,a\,b$ knowing $a\,b$ and angles $g\,a\,b$ and $g\,b\,a$. R_2 can then be found by (16).

Given R_1, R_2, I_1 and I_2 to find $a\,b$, angles $g\,a\,b$ and $g\,b\,a$ and T_1, T_2, Draw $a\,f$ in Fig. 21,

$$a\,f\,b = 180° - \tfrac{1}{2}(I_1 + I_2)$$

$a\,f$ and $f\,b$ can be computed, being the chords of curves $a\,f$ and $f\,b$. Knowing angle $a\,f\,b$ and sides $a\,f$ and $f\,b$, the triangle $a\,f\,b$ is capable of solution whence $a\,b$ and angle $b\,a\,f$ and $f\,b\,a$ may be found.

$$g\,a\,b = b\,a\,f + \tfrac{1}{2} I_1$$
$$g\,b\,a = f\,b\,a + \tfrac{1}{2} I_2$$
$$a\,g\,b = 180° - (g\,a\,b + g\,b\,a)$$

One side and two angles of the triangle $a\,g\,b$ are known, hence the other two sides T_1 and T_2 can be found.

15. Curve Location

General Principles (12). "Changes in direction should as far as practicable be made coincident with breaks in the grade line, curves should be made of as large radius as obtainable, and reverse curves always avoided, by placing at least 30 ft of tangent between the parts. A short tangent should not be placed between curves of the same direction, but a very flat curve used in its place. The standard minimum radius of curvature in the open country is 300 ft; where an unavoidable right angled turn occurs at a highway junction, 200 ft should be used; and nothing less will be allowed without special permission except at thickly settled street corners."

A curve may be located or staked out in the field by one of several methods. Up to 200 ft in length, a satisfactory location can usually be obtained by measuring off the external and tangent distances, which gives three points on the curve, one at each end and one in the middle. Starting with the P. C. and measuring off the proper distances intermediate points between the P. C. and mid point and the mid point and P. T., corresponding to the 50 or 100-ft stations of the line are found. These points are lined in by eye, being guided by the mid point and P. C. and P. T., so that a smooth curve will result. When a longer curve than 200 ft is to be staked out or when a more accurate location is desired, it is advisable to use one of the following methods. The tables referred to below are included in Art. 16.

By Transit and Tape. The intersection angle I and either the external E or tangent T are usually measured in the field. From these known values, it is possible by formulas (1) to (15) to compute R or D. D may also be found from Table IV as previously explained, or R may be found from Table VII and the corresponding value of D from Table VI.

Example. Let measured values of I and T be 30° 20′ and 150 ft respectively. From (3) $R = 553.36$ ft or from Table VII, $R = 368.91 \times 1.5 = 553.35$ ft. From Table VI, $D = 10°\ 21'\ 30''$ or from Table IV, $D = 1553.1/150 = 10°\ 21'\ 30''$. The length of curve L: From (1) $L = 2\pi \times 553.36 \times 30.333/360 = 292.93$ ft, or from (2) $L = I/D = 292.93$ ft, or from Table VII $L = 292.96$ ft.

In Fig. 22 the curve to be located as calculated above is shown with the P. C. = Sta. 1 + 75. The station of the P. T. is 1 + 75 + L or 1.75 + 2.9293 or Sta. 4 + 67.93. It is desired to stake out the 50-ft stations around the curve. From Table II, it is seen that, with this degree of curve, 50-ft chords should be used in measuring around the curve. The stations to be staked are 2, 2 + 50, 3, 3 + 50, 4, 4 + 50 and the P.T. By formula (15) $\sin \tfrac{1}{2} D = C/2\,R$. For a 100-ft arc $D = 10°\ 21'\ 30''$. The value of D for any other length of arc is directly proportional to the lengths of the chords subtending the arcs. The first chord from Sta. 1 + 75 to Sta.

2 is 25 ft and the angle at the center subtended by it is $D\,25/100 = 2°\,35'\,20''$. The next five chords to Sta. 4 + 50 are 50 ft each and subtend an angle at the center of $D\,50/100 = 5°\,10'\,45''$. The last chord from Sta. 4 + 50 to the P. T. is 17.93 ft and subtends an angle of $D\,18/100 = 1°\,51'$. In Fig. 22 draw the broken lines from the P. C. to the different stations around the curve. The deflection angle $g\,a\,f$ for Sta. 3 is one-half angle $a\,o\,f$. Similarly the angle between the tangent $a\,g$ and any other chord joining the P. C. and a point on the curve is always one-half the angle at the center subtended by the chord. To lay out the curve set the transit up over the P. C. with the telescope reversed and verniers of the horizontal plate at zero. Sight on some point of the transit line and clamp the lower motion. Plunge the telescope and the line of sight will then be coincident with $a\,g$ of Fig. 22. Turn off the deflection angle for Sta. 2 which is one-half of 2° 35′ 20″ or 1° 17′ 40″. The line of sight will now coincide with a 2 in the figure. Measure with the tape 25 ft from the P. C. along this line and Sta. 2 is located. To locate Sta. 2 + 50 increase the angle for Sta. 2 by adding one-half of 5° 10′ 45″ making the total angle now read 3° 53′ 2″. The line of sight is now coincident with line a 2+ in the figure. Measure 50 ft with the tape from Sta. 2 already located and set a point on the line, a 2+ which will locate Sta. 2 + 50. In a similar manner Stas. 3, 3 + 50, 4, and 4 + 50 are located by increasing the angle each time by 2° 35′ 22″ and measuring 50-ft chords from stations previously located. The P. T. does not come at a regular station interval hence the shortened chord and its corresponding subtended angle have to be taken into account in figuring the deflection angle in the same manner as for Sta. 2. As a check on the work the total angle turned off to locate the P. T. from the P. C. or angle $g\,a\,b$ should be exactly ½ I or 15° 10′. The deflection angles of the various stations and total angles with the transit at the P. C. are as follows:

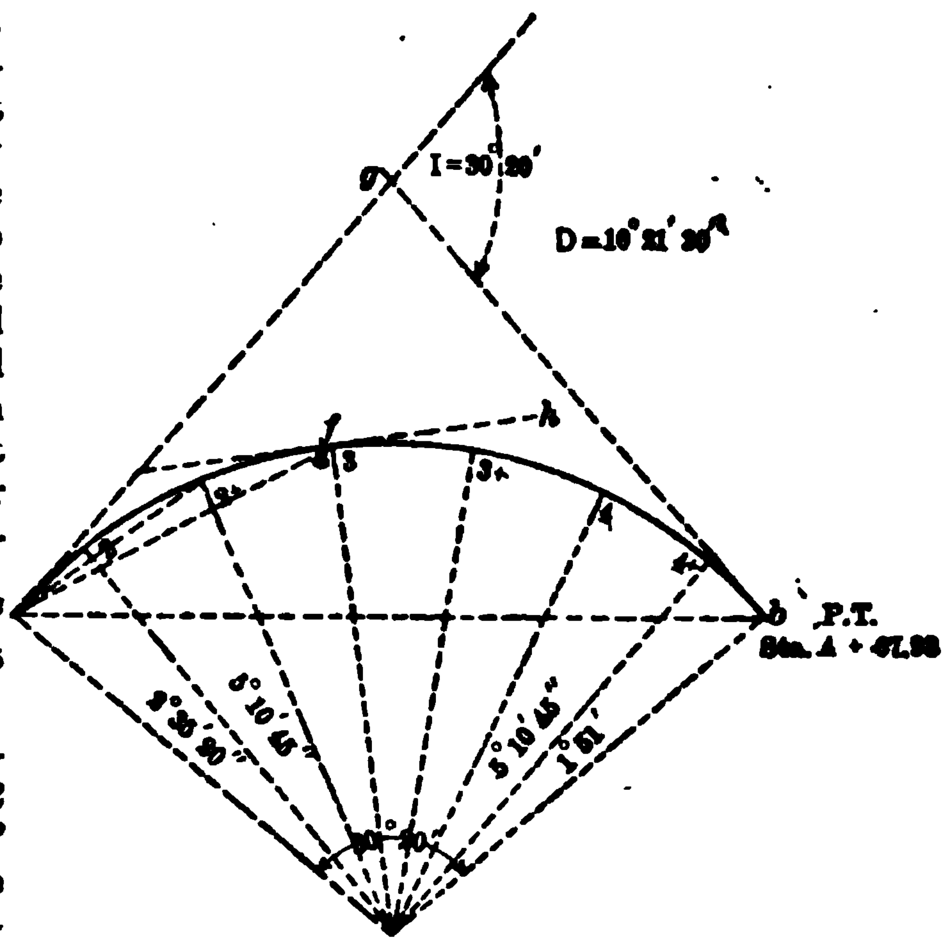

Fig. 22

	Deflection Angle	Total Angle
Sta. 2	1° 17′ 40″	
Sta. 2 + 50	2° 35′ 22″	3° 53′ 2″
Sta. 3	2° 35′ 22″	6° 28′ 24″
Sta. 3 + 50	2° 35′ 22″	9° 3′ 46″
Sta. 4	2° 35′ 22″	11° 39′ 8″
Sta. 4 + 50	2° 35′ 22″	14° 14′ 30″
P. T. Sta. 4 + 67.93	0° 55′ 30″	15° 10′ 0″

It is better to carry the calculations for the angles to seconds so that the computations will check. The angles should be turned off on the transit as near the calculated values as the reading of the verniers will permit. Altho measurements are made along chords instead of arcs, if the chord length used is varied according to the degree of curve, as per Table II, the difference in the length obtained is well within the accuracy desired.

When it is impossible to see the P. T. from the P. C., the above method of laying out the curve is slightly modified. Take the previous example and suppose that the station beyond Sta. 3 cannot be seen from the P. C. Proceed as follows: After locating Sta. 3, set up the transit over this station. Sight back on the P. C. which makes the line of sight coincide with line *a f* in Fig. 22. Plunge the telescope and turn off, in a direction corresponding to the flexure of the curve, the same total angle that was used in locating this station from the P. C. or 6° 28′ 24″. This brings the line of sight tangent to the curve at *f* or coincident with *f h*. By turning off the proper deflection angles, the other stations of the curve can be located from this set-up similarly to the way it was accomplished from the P. C. In order that the reading of the angles on the instrument may be the same as if the curve was located entirely from the P. C., the verniers should be set at zero when the transit is moved to Sta. 3. Then when the angle 6° 28′ 24″ is turned off to bring line of sight into tangency with the curve at this point and the deflection angle to Sta. 3 + 50 is added and turned off, the vernier will read 9° 3′ 46″ or the same as if Sta. 3 + 50 had been located from the P. C. Suppose the P. T. in this curve cannot be seen until Sta. 4 + 50 is reached, this latter point being located from the set-up at Sta. 3. Set up transit over Sta. 4 + 50, sight back on Sta. 3. Bring the line of sight tangent to the curve by turning off one-half the central angle included between Stas. 3 and 4 + 50, add the deflection angle for the next station, in this case the P. T., and proceed as before. To make notes continuous when the transit is moved to Sta. 4 + 50, set the verniers before sighting back on Sta. 3 so that the angle read is 6° 28′ 24″. When the angle is turned off to bring the line of sight tangent to the curve at 4 + 50, the verniers will read 14° 14′ 30″ and adding the deflection angle to the next station, in this case the P. T., the verniers will read 15° 10′.

Sta.	Deflection Angle	Index Reading	Total Angle	Calculated Bearing	Magnetic Bearing	Remarks
11 + 50						
11				N. 55° 30′ E.	N. 55° 30′ E.	
10 + 75	1° 15′	25° 0′	50° 0′			P. T.
10 + 50	2° 30′	23° 45′				
10	2° 30′	21° 15′				
9 + 50	2° 30′	18° 45′				
9	2° 30′	16° 15′				
8 + 50	2° 30′	13° 45′				
8	2° 30′	11° 15′				
7 + 50	2° 30′	8° 45′				
7	2° 30′	6° 15′				10° curve right
6 + 50	2° 30′	3° 45′				I = 50°
6	1° 15′	1° 15′				L = 500′
5 + 75	P.C. 10°	C. R.				R = 573′
5 + 50				N. 5° 30′ E.	N. 5° 28′ E.	

Fig. 23. Curve Notes

When the P. T. is reached, it is necessary to make the line of sight coincident with the tangent beyond the P. T. If the intersection of the tangents is not visible or accessible from the P. T. proceed as follows: Set

p the transit over the P. T. and sight back to any visible station on the rve, and turn off in a direction towards the P. I., one-half the central ngle between the station sighted on and the P. T. Plunge the telescope nd the line of sight is then tangent to the curve at the P. T.

Data for running the curve may also be obtained from Table VII as shown the explanation preceding the table. One form of field notes recording rve layouts is shown in Fig. 23.

By Tangent Offsets. This method is used sometimes in laying out curves avoid obstacles that would interfere with the method of deflections. simple case is shown in Fig. 24. D_1, D and D_2 are the angles at the center subtended by he arcs $a\,x$, $x\,x_1$, $x_1\,x_2$ . . . $x_4 b$. It is necesary to find the coördinates $a\,n$, $n\,x$, $a\,n_1$, $n_1\,x_1$ . . . $b\,m$, $m\,x_4$ and so on of the different tations, x. In the triangle $a\,n\,x$, angle $a\,o\,x = D_1$, then $a\,x = 2\,R \sin \frac{1}{2} D_1$, see formula (8). n triangle $a\,n\,x$, angle $n\,a\,x = \frac{1}{2} D_1$, $a\,n = a\,x$ os $\frac{1}{2} D_1$ and $n\,x = a\,x \sin \frac{1}{2} D_1$ or $a\,n = R$ in D_1 and $n\,x = 2\,R \sin^2 \frac{1}{2} D_1$. In triangle $a\,o\,x_1$, angle $a\,o\,x_1 = D_1 + D$, $a\,x_1 = 2\,R$ sin $\frac{1}{2}(D_1 + D)$ and in triangle $a\,n_1\,x_1$, $n_1\,a\,x_1 = \frac{1}{2}(D_1 + D)$, $a\,n_1 = R \sin (D_1 + D)$ and $n_1\,x_1 = 2\,R \sin^2 \frac{1}{2}(D_1 + D)$. Coördinates for other points on the curve are found in a similar manner. When the coördinates of a station are known, it may be located in the field in either of the following ways. Take for example Sta. x_1. Measure $a\,n_1$ along the tangent, set up the transit at n_1, turn off 90° and measure $n_1\,x_1$. Where the perpendicular offsets to the tangent are not too long, a curve may be conveniently laid out by a second method without using a transit. First measure $a\,n_1$ along the tangent as in the previous method. Then with a tape strike an arc with n_1 as a center and $n_1\,x_1$ as a radius and with station x, previously located, as a center and a radius of $x\,x_1$, strike an arc. The intersection of the two arcs locates the point. The last method is facilitated by using two tapes.

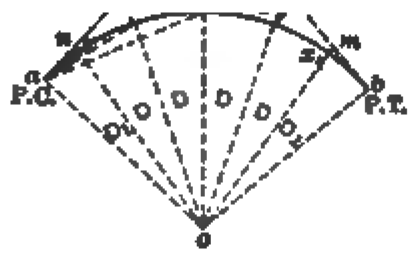

Fig. 24

Parabolic Curves may be located by offsets from the tangents. In Fig. 28 assume that $a\,g$ and $g\,b$ are two equal tangents, a being the P. C. and b the P. T. of the curve. If point a is visible from b measure $b\,d = \frac{1}{2} a\,b$. Measure $d\,f = \frac{1}{2} d\,g$. f is the mid point of the parabolic curve. Other points on the curve can be determined by measuring perpendicular offsets from the tangents $a\,g$ and $g\,b$. These offsets are calculated as follows: Take any point c on tangent $a\,g$, the perpendicular offset from c to the curve $= \left(\frac{a\,c}{a\,g}\right)^2 g\,f$. Sufficient points are determined on the curve so that its alignment is known. The length and stationing of the curve is determined by measuring around it with a tape using 50-ft chords. In case the P. C. and P. T. of the curve are not intervisible, it might be found that the chord connecting points half way between the P. I. and P. C., and P. I. and P. T. could be seen thru its length. For example, in Fig. 28 assume $a\,g$ and $g\,b$ each equal to one-half the tangent distance and that a can be seen from b. Measure $b\,d$ and $g\,d$ as before. d is now the mid point of the curve and offsets to other points on the curve would be calculated as follows: Offset $= (x/2\,a\,g)^2\,g\,d$ where x is the distance measured from the P. C. or P. T. to the point from which the offset is to be measured. Measuring

the offsets perpendicular to the tangents does not comply strictly with the law of the parabola, but the error involved is so slight that it can be neglected.

By Offsets from the Long Chord. Instances may occur where this method is the most convenient one to use. In Fig. 25, $m_2 x_2$ = the mid-ordinate of the curve or from equation (6A) $M = R(1 - \cos \frac{1}{2} I)$. The length of $a\,b$ from equation (8) is $C = 2R \sin \frac{1}{2} I$. Similarly, $m_2\,n_2 = R[1 - \cos \frac{1}{2}(4D)]$ and $m\,m_4 = 2R \sin \frac{1}{2} 4D$, therefore, for station m, $a\,x = \frac{1}{2}C - \frac{1}{2}m\,m_4$ and $m\,x = M - m_2 n_2$. The coördinates for the other stations are found in a similar manner.

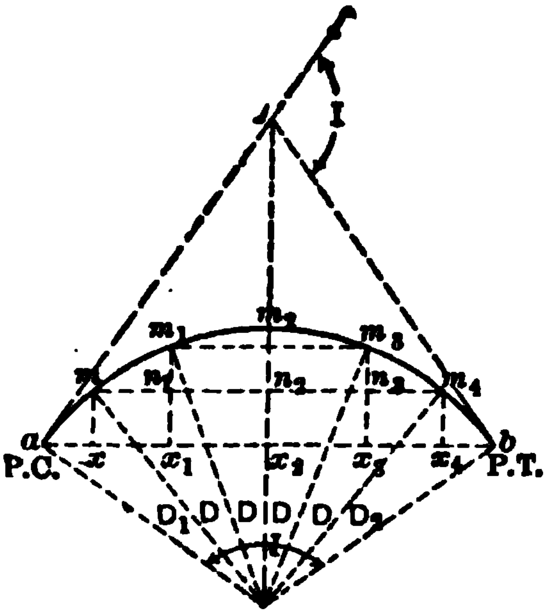

Fig. 25

To Pass an Obstacle on the Curve. Suppose in Fig. 26 the curve is being located with the transit at a. The obstacle q prevents Sta. m_3 from being seen. The instrument may be moved to some other station on the curve, such as m_2, which has been set from a and from which m_3 is visible, and the curve continued from this point. With the transit at a one method is to set a plus station n on the curve and another station n_1 just 100 ft from n. Turn off the angle for Sta. m_4 and measure from n_1 a distance $n_1\,m_4 = 100 - m_2\,n$. Another method with transit at a is to turn off an angle to some full station such as m_4 and measure off on this line the calculated chord $a\,m_4$. This locates m_4 and the invisible stations from a may be located by setting up at m_4 and working back along the curve. See (1), (11) and (15).

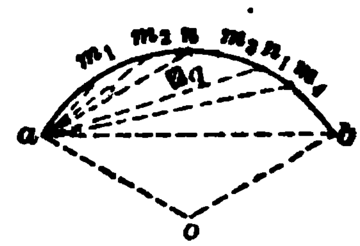

Fig. 26

To Locate Curve when P. C. or P. T. is Inaccessible. In Fig. 27 suppose it is impossible to occupy a, the P. C. Set transit over b, the P. T. which has been located from g, and run curve back from P. T. towards the P. C., setting a point m on the curve as near the P. C. as possible. Check the location of m by calculating and measuring the tangent offset $n\,m$ from the tangent $a\,g$. If the P. T. is inaccessible instead of the P. C., this same method can be used except the curve will be run from the P. C. towards the P. T.

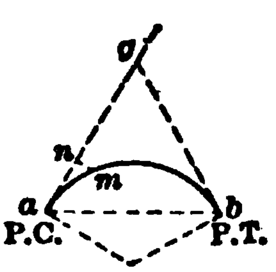

Fig. 27

To Find I when P. T. is Inaccessible. In Fig. 28, g, the P. I. of the tangents, is inaccessible, and the angle I must be known before the curve can be figured. From any point a on the tangent $a\,g$ run a line $a\,b$ to a point b on the tangent $g\,b$. Measure $a\,b$ and angles $g\,a\,b$ and $g\,b\,a$. From geometry $I = g\,a\,b + g\,b\,a$. In the triangle $g\,a\,b$ the lengths of the sides $a\,g$ and $g\,b$ may be calculated since one side and two angles of the triangle are known. The distances from a and b to the P. C. and P. T. respectively will then be the tangent distance T of the curve minus $a\,g$ for the P. C. and T minus $g\,b$ for the P. T.

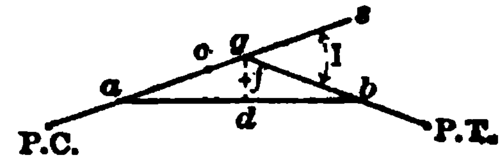

Fig. 28

16. Curve Tables

Table of Functions of 1° Curve. For the purpose of facilitating computations Table IV has been prepared giving the externals and tangents

for a 1° curve for intersection angles varying by 10 min from 1° to 120° 50′. Approximate values of the tangent and external to any other degree of curve may be found by dividing the tabular values opposite the given central angle by the given degree of curve, expressed in degrees.

To illustrate the use of the Table IV, assume an intersection angle of 38° 20′ and a 4° curve. The length of tangent and external for a 1° curve in the table corresponding to an intersection angle of 38° 20′ is 1991.5 ft and 336.25 ft respectively. For a 4° curve the tangent would be 1991.5/4 = 497.9 ft and the external 336.25/4 = 84.06 ft. Conversely if the tangent or external is known together with the intersection angle, the degree of curve may be obtained by dividing the tabular value of the tangent or external by the measured tangent or external.

Mass. Highway Comm. Curve Tables* compiled by A. M. Lovis, First Assistant Engineer.

THE CURVE FUNCTIONS IN TABLE VII are computed on the basis of tangent distances of 100 ft for different intersection angles varying by one minute of arc from 0° 30′ to 90°. In the accompanying figure $a\,c = b\,c = 100$ ft, angle Δ = the intersection angle between the tangents and also the angle at the center, $c\,e$ = the external distance or distance from point of intersection of the tangents to the mid-point of the curve, $a\,o$ = the radius of the curve, and $a\,e\,b$ = the length of the arc measured around the curve.

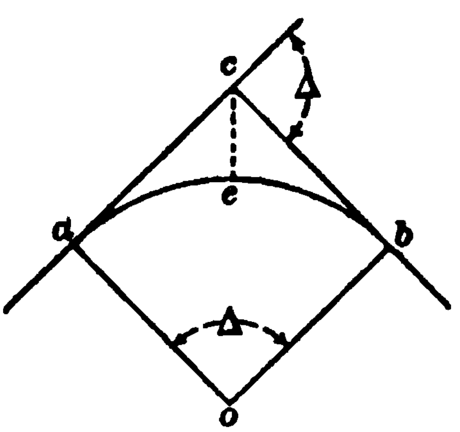

Fig. 29

FOR TANGENT DISTANCES OTHER THAN 100 FT in length, the tabular values of the external, radius, and arc must be multiplied by the ratio of the given tangent to 100. For example, suppose the tangent to be used is 150 ft and the angle Δ is 30° 20′. The ratio of 150 to 100 is 1.5 and the tabular values of the different functions multiplied by this ratio give the following values: external = 13.3 × 1.5 = 20.0; radius = 368.909 × 1.5 = 553.364; length of arc = 195.307 × 1.5 = 292.961. In a similar manner a value may be assumed for an external, a radius or an arc function. Dividing this value by the tabular value of the same function gives the ratio by which the tabular functions must be multiplied to obtain the required values. For example, suppose the external required is 20 ft and angle Δ = 30° 20′. The tangent, radius, and arc for this curve would be found by multiplying the tabular values by 20/13.3 or 1.5.

CORRECTIONS TO APPLY TO THE RADIUS, when angle Δ is not given in even minutes, are given in the column headed Diff 10″. For example, the value of the radius for an angle Δ = 30° 20′ 40″, with tangent lengths of 100 ft, would be 368.909 − 4 (0.035) = 368.769. If the tangents were 150 ft in length and angle Δ had the same value, the radius would be 368.769 × 1.5 = 553.154.

DEFLECTION ANGLES for arc lengths of 100 ft are given in the sixth column of the table. If it is desired to stake out points on a curve at 100-ft intervals measured around the curve, the value given in the sixth column would be used for the deflection angle, while the chord used to locate the points would be twice the value of the chord for a 50-ft arc stated at the top of the table

* The tables were furnished by the Massachusetts Highway Commission. They may be copied without liability for damages on account of the copyright.

Table IV.—Tangents and Externals

1°	50.00	.218	11	551.[illegible]	26.500	21°	1061.9	97.577
10′	58.34	.297	10′	560.11	27.313	10′	1070.6	99.155
20	66.67	.388	20	568.53	28.137	20	[illegible]	100.75
30	75.01	.491	30	576.95	28.974	30	[illegible]	102.35
40	83.34	[illegible]	40	585.36	29.824	40	1096.4	103.97
50	91.68	.733	50	593.79	30.686	50	1105.1	105.60
2	100.01	.873	12	602.21	[illegible]	22	1113.7	107.24
10	108.35	1.024	10	610.64	32.447	10	1122.4	108.90
20	116.69	1.188	20	619.07	[illegible]	20	1131.0	110.57
30	125.02	1.364	30	627.50	34.259	30	1139.7	112.25
40	133.36	1.552	40	635.93	35.183	40	1148.4	113.95
50	141.70	1.752	50	644.37	36.120	50	1157.0	115.66
3	150.04	1.964	13	652.81	37.070	23	1165.7	117.38
10	158.38	2.188	10	661.25	38.031	10	1174.4	119.12
20	[illegible].72	2.425	20	669.70	[illegible]	20	1183.1	120.87
30	175.06	2.674	30	678.15	39.993	30	1191.8	122.63
40	183.40	2.934	40	686.60	[illegible]	40	1200.5	124.41
50	191.74	3.207	50	695.06	42.004	50	1209.2	126.20
4	200.08	3.492	14	703.51	[illegible]	24	1217.9	128.00
10	208.[illegible]	3.790	10	711.97	44.066	10	1226.6	129.82
20	216.77	4.099	20	720.[illegible]	45.116	20	1235.3	131.65
30	225.12	4.421	30	728.90	46.178	30	1244.0	133.50
[illegible]	233.47	4.755	40	737.37	47.253	40	1252.8	135.35
50	241.81	5.100	50	745.85	48.341	50	1261.5	137.23
5	250.[illegible]	5.459	15	754.32	49.441	25	1270.2	139.[illegible]
10	258.51	5.829	10	762.80	50.554	10	1279.0	141.01
20	266.86	6.211	20	771.29	51.679	20	1287.7	142.93
30	275.21	6.606	30	779.77	52.818	30	1296.5	144.85
40	283.57	7.013	40	788.26	53.969	40	1305.3	146.79
50	291.92	7.432	50	796.75	55.132	50	1314.0	148.75
6	300.28	7.863	16	805.25	56.309	26	1322.8	150.71
10	308.64	8.307	10	813.75	57.498	10	1331.6	152.69
20	316.99	8.762	20	822.25	58.699	20	1340.4	154.69
30	325.35	9.230	30	830.[illegible]	59.914	30	1349.2	156.70
40	333.71	9.710	40	839.27	61.141	40	1358.0	158.[illegible]
50	342.08	10.202	50	847.78	62.381	50	1366.8	160.76
7	350.44	10.707	17	856.30	63.634	27	1375.6	162.[illegible]
10	358.81	11.224	10	864.82	64.900	10	[illegible]	164.86
20	367.17	11.753	20	873.35	66.178	20	1393.2	166.95
30	375.54	12.294	30	881.88	67.470	30	1402.0	169.04
40	383.91	12.847	40	890.41	68.774	40	1410.9	171.15
50	392.28	13.413	50	898.95	70.091	50	1419.7	173.27
8	400.66	13.991	18	907.49	71.421	28	1428.6	175.41
10	409.03	14.582	10	916.03	72.764	10	1437.4	177.55
20	417.41	15.184	20	924.58	74.119	20	1446.3	179.72
30	425.79	15.799	30	933.13	75.488	30	1455.1	181.89
40	434.17	[illegible]	40	941.69	76.869	40	1464.0	[illegible].08
50	442.55	17.065	50	950.25	78.264	50	1472.9	186.29
9	450.93	17.717	19	958.81	79.671	29	1481.8	188.51
10	459.32	18.381	10	967.38	81.092	10	1490.7	190.74
20	467.71	19.058	20	975.96	82.525	20	1499.6	192.99
30	476.10	19.746	30	984.53	83.972	30	1508.5	195.25
40	484.[illegible]	20.447	40	993.12	85.431	[illegible]	1517.4	197.53
50	492.88	21.161	50	1001.7	86.904	50	1526.3	199.82
10	501.28	21.887	20	1010.3	88.389	30	1535.3	202.12
10	509.68	22.624	10	1018.9	89.888	10	1544.2	204.44
20	518.08	23.375	20	1027.5	91.399	20	1553.1	206.77
30	526.48	24.138	30	1036.1	92.924	30	1562.1	209.12
40	534.89	24.913	40	1044.7	94.462	40	1571.0	211.[illegible]
50	543.29	25.700	50	1053.3	96.013	50	1580.0	213.86

To a 1° Curve (15)

Angle Δ	Tangent T.	External E.	Angle Δ	Tangent T.	External E.	Angle Δ	Tangent T.	External E.
31°	1589.0	216.25	41°	2142.2	387.38	51°	2732.9	618.39
10′	1598.0	218.66	10′	2151.7	390.71	10′	2743.1	622.81
20	1606.9	221.08	20	2161.2	394.06	20	2753.4	627.24
30	1615.9	223.51	30	2170.8	397.43	30	2763.7	631.69
40	1624.9	225.96	40	2180.3	400.82	40	2773.9	636.17
50	1633.9	228.42	50	2189.9	404.22	50	2784.2	640.66
32	1643.0	230.90	42	2199.4	407.64	52	2794.5	645.17
10	1652.0	233.39	10	2209.0	411.07	10	2804.9	649.70
20	1661.0	235.90	20	2218.6	414.52	20	2815.2	654.25
30	1670.0	238.43	30	2228.1	417.99	30	2825.6	658.83
40	1679.1	240.96	40	2237.7	421.48	40	2835.9	663.42
50	1688.1	243.52	50	2247.3	424.98	50	2846.3	668.03
33	1697.2	246.08	43	2257.0	428.50	53	2856.7	672.66
10	1706.3	248.66	10	2266.6	432.04	10	2867.1	677.32
20	1715.3	251.26	20	2276.2	435.59	20	2877.5	681.99
30	1724.4	253.87	30	2285.9	439.16	30	2888.0	686.68
40	1733.5	256.50	40	2295.6	442.75	40	2898.4	691.40
50	1742.6	259.14	50	2305.2	446.35	50	2908.9	696.13
34	1751.7	261.80	44	2314.9	449.98	54	2919.4	700.89
10	1760.8	264.47	10	2324.6	453.62	10	2929.9	705.66
20	1770.0	267.16	20	2334.3	457.27	20	2940.4	710.46
30	1779.1	269.86	30	2344.1	460.95	30	2951.0	715.28
40	1788.2	272.58	40	2353.8	464.64	40	2961.5	720.11
50	1797.4	275.31	50	2363.5	468.35	50	2972.1	724.97
35	1806.6	278.05	45	2373.3	472.08	55	2982.7	729.85
10	1815.7	280.82	10	2383.1	475.82	10	2993.3	734.76
20	1824.9	283.60	20	2392.8	479.59	20	3003.9	739.68
30	1834.1	286.39	30	2402.6	483.37	30	3014.5	744.62
40	1843.3	289.20	40	2412.4	487.17	40	3025.2	749.59
50	1852.5	292.02	50	2422.3	490.98	50	3035.8	754.57
36	1861.7	294.86	46	2432.1	494.82	56	3046.5	759.58
10	1870.9	297.72	10	2441.9	498.67	10	3057.2	764.61
20	1880.1	300.59	20	2451.8	502.54	20	3067.9	769.66
30	1889.4	303.47	30	2461.7	506.42	30	3078.7	774.73
40	1898.6	306.37	40	2471.5	510.33	40	3089.4	779.83
50	1907.9	309.29	50	2481.4	514.25	50	3100.2	784.94
37	1917.1	312.22	47	2491.3	518.20	57	3110.9	790.08
10	1926.4	315.17	10	2501.2	522.16	10	3121.7	795.24
20	1935.7	318.13	20	2511.2	526.13	20	3132.6	800.42
30	1945.0	321.11	30	2521.1	530.13	30	3143.4	805.62
40	1954.3	324.11	40	2531.1	534.15	40	3154.2	810.85
50	1963.6	327.12	50	2541.0	538.18	50	3165.1	816.10
38	1972.9	330.15	48	2551.0	542.23	58	3176.0	821.37
10	1982.2	333.19	10	2561.0	546.30	10	3186.9	826.66
20	1991.5	336.25	20	2571.0	550.39	20	3197.8	831.98
30	2000.9	339.32	30	2581.0	554.50	30	3208.8	837.31
40	2010.2	342.41	40	2591.1	558.63	40	3219.7	842.67
50	2019.6	345.52	50	2601.1	562.77	50	3230.7	848.06
39	2029.0	348.64	49	2611.2	566.94	59	3241.7	853.46
10	2038.4	351.78	10	2621.2	571.12	10	3252.7	858.89
20	2047.8	354.94	20	2631.3	575.32	20	3263.7	864.34
30	2057.2	358.11	30	2641.4	579.54	30	3274.8	869.82
40	2066.6	361.29	40	2651.5	583.78	40	3285.8	875.32
50	2076.0	364.50	50	2661.6	588.04	50	3296.9	880.84
40	2085.4	367.72	50	2671.8	592.32	60	3308.0	886.38
10	2094.9	370.95	10	2681.9	596.62	10	3319.1	891.95
20	2104.3	374.20	20	2692.1	600.93	20	3330.3	897.54
30	2113.8	377.47	30	2702.3	605.27	30	3341.4	903.15
40	2123.3	380.76	40	2712.5	609.62	40	3352.6	908.79
50	2132.7	384.06	50	2722.7	614.00	50	3363.8	914.45

Table IV.—Tangents and Externals

Angle Δ	Tangent T.	External E.	Angle Δ	Tangent T.	External E.	Angle Δ	Tangent T.	External E.
61°	3375.0	920.14	71°	4086.9	1308.2	81°	4893.6	1805.3
10′	3386.3	925.85	10′	4099.5	1315.6	10′	4908.0	1814.7
20	3397.5	981.58	20	4112.1	1322.9	20	4922.5	1824.1
30	3408.8	927.34	30	4124.8	1330.3	30	4937.0	1833.6
40	3420.1	943.12	40	4137.4	1337.7	40	4951.5	1843.1
50	3431.4	948.92	50	4150.1	1345.1	50	4966.1	1852.6
62	3442.7	954.75	72	4162.8	1352.6	82	4980.7	1862.2
10	3454.1	960.60	10	4175.6	1360.1	10	4995.4	1871.8
20	3465.4	966.48	20	4188.5	1367.6	20	5010.0	1881.5
30	3476.8	972.38	30	4201.2	1375.2	30	5024.8	1891.2
40	3488.3	978.31	40	4214.0	1382.8	40	5039.5	1900.9
50	3499.7	984.27	50	4226.8	1390.4	50	5054.3	1910.7
63	3511.1	990.24	73	4239.7	1398.0	83	5069.2	1920.5
10	3522.6	996.24	10	4252.6	1405.7	10	5084.0	1930.4
20	3534.1	1002.3	20	4265.6	1413.5	20	5099.0	1940.3
30	3545.6	1008.3	30	4278.5	1421.2	30	5113.9	1950.3
40	3557.2	1014.4	40	4291.5	1429.0	40	5128.9	1960.2
50	3568.7	1020.5	50	4304.6	1436.8	50	5143.9	1970.3
64	3580.3	1026.6	74	4317.6	1444.6	84	5159.0	1980.4
10	3591.9	1032.8	10	4330.7	1452.5	10	5174.1	1990.5
20	3603.5	1039.0	20	4343.8	1460.4	20	5189.3	2000.6
30	3615.1	1045.2	30	4356.9	1468.4	30	5204.4	2010.8
40	3626.8	1051.4	40	4370.1	1476.4	40	5219.7	2021.1
50	3638.5	1057.7	50	4383.3	1484.4	50	5234.9	2031.4
65	3650.2	1063.9	75	4396.5	1492.4	85	5250.3	2041.7
10	3661.9	1070.2	10	4409.8	1500.5	10	5265.6	2052.1
20	3673.7	1076.6	20	4423.1	1508.6	20	5281.0	2062.5
30	3685.4	1082.9	30	4436.4	1516.7	30	5296.4	2073.0
40	3697.2	1089.3	40	4449.7	1524.9	40	5311.9	2083.5
50	3709.0	1095.7	50	4463.1	1533.1	50	5327.4	2094.1
66	3720.9	1102.2	76	4476.5	1541.4	86	5343.0	2104.7
10	3732.7	1108.6	10	4489.9	1549.7	10	5358.6	2115.3
20	3744.6	1115.1	20	4503.4	1558.0	20	5374.2	2126.0
30	3756.5	1121.7	30	4516.9	1566.3	30	5389.9	2136.7
40	3768.5	1128.2	40	4530.4	1574.7	40	5405.6	2147.5
50	3780.4	1134.8	50	4544.0	1583.1	50	5421.4	2158.4
67	3792.4	1141.4	77	4557.6	1591.6	87	5437.2	2169.2
10	3804.4	1148.0	10	4571.2	1600.1	10	5453.1	2180.2
20	3816.4	1154.7	20	4584.8	1608.6	20	5469.0	2191.1
30	3828.4	1161.3	30	4598.5	1617.1	30	5484.9	2202.2
40	3840.5	1168.1	40	4612.2	1625.7	40	5500.9	2213.2
50	3852.6	1174.8	50	4626.0	1634.4	50	5517.0	2224.3
68	3864.7	1181.6	78	4639.8	1643.0	88	5533.1	2235.5
10	3876.8	1188.4	10	4653.6	1651.7	10	5549.2	2246.7
20	3889.0	1195.2	20	4667.4	1660.5	20	5565.4	2258.0
30	3901.2	1202.0	30	4681.3	1669.2	30	5581.6	2269.3
40	3913.4	1208.9	40	4695.2	1678.1	40	5597.8	2280.6
50	3925.6	1215.8	50	4709.2	1686.9	50	5614.2	2292.0
69	3937.9	1222.7	79	4723.2	1695.8	89	5630.5	2303.5
10	3950.2	1229.7	10	4737.2	1704.7	10	5646.9	2315.0
20	3962.5	1236.7	20	4751.2	1713.7	20	5663.4	2326.6
30	3974.8	1243.7	30	4765.3	1722.7	30	5679.9	2338.2
40	3987.2	1250.8	40	4779.4	1731.7	40	5696.4	2349.8
50	3999.5	1257.9	50	4793.6	1740.8	50	5713.0	2361.5
70	4011.9	1265.0	80	4807.7	1749.9	90	5729.7	2373.3
10	4024.4	1272.1	10	4822.0	1759.0	10	5746.3	2385.1
20	4036.8	1279.3	20	4836.2	1768.2	20	5763.1	2397.0
30	4049.3	1286.5	30	4850.5	1777.4	30	5779.9	2408.9
40	4061.8	1293.6	40	4864.8	1786.7	40	5796.7	2420.9
50	4074.4	1300.9	50	4879.2	1796.0	50	5813.6	2432.9

To a 1° Curve (15)

Angle Δ	Tangent T.	External E.	Angle Δ	Tangent T.	External E.	Angle Δ	Tangent T.	External E.
91°	5830.5	2444.9	101°	6950.6	3278.1	111°	8336.7	4386.1
10′	5847.5	2457.1	10′	6971.3	3294.1	10′	8362.7	4407.6
20	5864.6	2469.3	20	6992.0	3310.1	20	8388.9	4429.2
30	5881.7	2481.5	30	7012.7	3326.1	30	8415.1	4450.9
40	5898.8	2493.8	40	7033.6	3342.3	40	8441.5	4472.7
50	5916.0	2506.1	50	7054.5	3358.5	50	8468.0	4494.6
92	5933.2	2518.5	102	7075.5	3374.9	112	8494.6	4516.6
10	5950.5	2531.0	10	7096.6	3391.2	10	8521.3	4538.8
20	5967.9	2543.5	20	7117.8	3407.7	20	8548.1	4561.1
30	5985.3	2556.0	30	7139.0	3424.3	30	8575.0	4583.4
40	6002.7	2568.6	40	7160.3	3440.9	40	8602.1	4606.0
50	6020.2	2581.3	50	7181.7	3457.6	50	8629.3	4628.6
93	6037.8	2594.0	103	7203.2	3474.4	113	8656.6	4651.3
10	6055.4	2606.8	10	7224.7	3491.3	10	8684.0	4674.2
20	6073.1	2619.7	20	7246.3	3508.2	20	8711.5	4697.2
30	6090.8	2632.6	30	7268.0	3525.2	30	8739.2	4720.3
40	6108.6	2645.5	40	7289.8	3542.4	40	8767.0	4743.6
50	6126.4	2658.5	50	7311.7	3559.6	50	8794.9	4766.9
94	6144.3	2671.6	104	7333.6	3576.8	114	8822.9	4790.4
10	6162.2	2684.7	10	7355.6	3594.2	10	8851.0	4814.1
20	6180.2	2697.9	20	7377.8	3611.7	20	8879.3	4837.8
30	6198.3	2711.2	30	7399.9	3629.2	30	8907.7	4861.7
40	6216.4	2724.5	40	7422.2	3646.8	40	8936 3	4885.7
50	6234.6	2737.9	50	7444.6	3664.5	50	8965.0	4909.9
95	6252.8	2751.3	105	7467.0	3682.3	115	8993.8	4934.1
10	6271.1	2764.8	10	7489.6	3700.2	10	9022.7	4958.6
20	6289.4	2778.3	20	7512.2	3718.2	20	9051.7	4983.1
30	6307.9	2792.0	30	7534.9	3736.2	30	9080.9	5007.8
40	6326.3	2805.6	40	7557.7	3754.4	40	9110.3	5032.6
50	6344.8	2819.4	50	7580.5	3772.6	50	9139.8	5057.6
96	6363.4	2833.2	106	7603.5	3791.0	116	9169.4	5082.7
10	6382.1	2847.0	10	7626.6	3809.4	10	9199.1	5107.9
20	6400.8	2861.0	20	7649.7	3827.9	20	9229.0	5133.3
30	6419.5	2875.0	30	7672.9	3846.5	30	9259.0	5158.8
40	6438.4	2889.0	40	7696.3	3865.2	40	9289.2	5184.5
50	6457.3	2903.1	50	7719.7	3884.0	50	9319.5	5210.3
97	6476.2	2917.3	107	7743.2	3902.9	117	9349.9	5236.2
10	6495.2	2931.6	10	7766.8	3921.9	10	9380.5	5262.3
20	6514.3	2945.9	20	7790.5	3940.9	20	9411.3	5288.6
30	6533.4	2960.3	30	7814.3	3960.1	30	9442.2	5315.0
40	6552.6	2974.7	40	7838.1	3979.4	40	9473.2	5341.5
50	6571.9	2989.2	50	7862.1	3998.7	50	9504.4	5368.2
98	6591.2	3003.8	108	7886.2	4018.2	118	9535.7	5395.1
10	6610.6	3018.4	10	7910.4	4037.8	10	9567.2	5422.1
20	6630.1	3033.1	20	7934.6	4057.4	20	9598.9	5449.2
30	6649.6	3047.9	30	7959.0	4077.2	30	9630.7	5476.5
40	6669.2	3062.8	40	7983.5	4097.1	40	9662.6	5504.0
50	6688.8	3077.7	50	8008.0	4117.0	50	9694.7	5531.7
99	6708.6	3092.7	109	8032.7	4137.1	119	9727.0	5559.4
10	6728.4	3107.7	10	8057.4	4157.3	10	9759.4	5587.4
20	6748.2	3122.9	20	8082.3	4177.5	20	9792.0	5615.5
30	6768.1	3138.1	30	8107.3	4197.9	30	9824.8	5643.8
40	6788.1	3153.3	40	8132.3	4218.4	40	9857.7	5672.3
50	6808.2	3168.7	50	8157.5	4239.0	50	9890.8	5700.9
100	6828.3	3184.1	110	8182.8	4259.7	120	9924.0	5729.7
10	6848.5	3199.6	10	8208.2	4280.5	10	9957.5	5758.6
20	6868.8	3215.1	20	8233.7	4301.4	20	9991.0	5787.7
30	6889.2	3230.8	30	8259.3	4322.4	30	0025.0	5817.0
40	6906.6	3246.5	40	8285.0	4343.6	40	10059.0	5846.5
50	6930.1	3262.3	50	8310.8	4364.8	50	10093.0	5876.1

multiplied by the cos of one-half the deflection angle for 100-ft chord. When the curve is staked out at 50-ft intervals, the deflection angle would be one-half the value given in the sixth column and the chord used to locate a point measured 50 ft around the curve would be the value stated at the top of the table. Deflection angles and chord distances for any other lengths of arc than 50 ft or 100 ft would be found by proportion. When tangent values other than 100 ft in length are used, the value of the radius for the given tangent length and angle Δ would be found as previously shown. The deflection angle in such a case would be the value found in the sixth column of the table opposite the value of the computed radius and the chord distances for a 50-ft arc would be at the top of the table in which the value of the computed radius occurs. For example, if the tangent is 150 ft and angle $\Delta = 30° 20'$, the computed radius = 553.364 ft. In the table the deflection angle for an arc of 100 ft, corresponding to a radius of 553.364 ft, is 5° 10.6′. The deflection angle for a 50-ft arc is hence 2° 35.3′ and the chord is 49.98 ft.

THE SKEW DISTANCES given in the last column of the table are computed for a 50-ft right-of-way. In the accompanying figure the distances $c\,d$ and $c\,d' = 25$ ft, being measured perpendicular to the center line of the right-of-way. The skew distances, $a\,b$ and $a\,b'$, are measured along the bisector of the angle $c\,a\,c'$ from the angle point a in the center line to the points of intersection, b and b', of the right-of-way lines. For any other width than 25 ft, the skew distance required is the distance in the table multiplied by the ratio of the width in question to 25 ft.

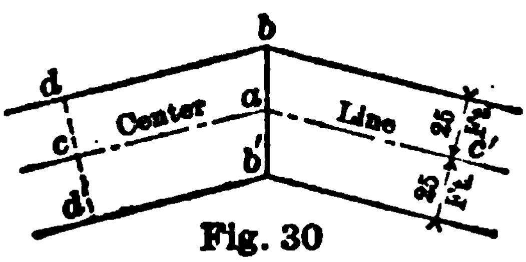

Fig. 30

Table V.—Minutes in Decimals of a Degree (11)

Min	Decimal	Min	Decimal	Min	Decimal	Min	Decimal	Min	Decimal
0′	.00000	12′	.20000	24′	.40000	36′	.60000	48′	.80000
30″	.00833	30″	.20833	30″	.40833	30″	.60833	30″	.80833
1′	.01667	13′	.21667	25′	.41667	37′	.61667	49′	.81667
30″	.02500	30″	.22500	30″	.42500	30″	.62500	30″	.82500
2′	.03333	14′	.23333	26′	.43333	38′	.63333	50′	.83333
30″	.04167	30″	.24167	30″	.44167	30″	.64167	30″	.84167
3′	.05000	15′	.25000	27′	.45000	39′	.65000	51′	.85000
30″	.05833	30″	.25833	30″	.45833	30″	.65833	30″	.85833
4′	.06667	16′	.26667	28′	.46667	40′	.66667	52′	.86667
30″	.07500	30″	.27500	30″	.47500	30″	.67500	30″	.87500
5′	.08333	17′	.28333	29′	.48333	41′	.68333	53′	.88333
30″	.09167	30″	.29167	30″	.49167	30″	.69167	30″	.89167
6′	.10000	18′	.30000	30′	.50000	42′	.70000	54′	.90000
30″	.10833	30″	.30833	30″	.50833	30″	.70833	30″	.90833
7′	.11667	19′	.31667	31′	.51667	43′	.71667	55′	.91667
30″	.12500	30″	.32500	30″	.52500	30″	.72500	30″	.92500
8′	.13333	20′	.33333	32′	.53333	44′	.73333	56′	.93333
30″	.14167	30″	.34167	30″	.54167	30″	.74167	30″	.94167
9′	.15000	21′	.35000	33′	.55000	45′	.75000	57′	.95000
30″	.15833	30″	.35833	30″	.55833	30″	.75833	30″	.95833
10′	.16667	22′	.36667	34′	.56667	46′	.76667	58′	.96667
30″	.17500	30″	.37500	30″	.57500	30″	.77500	30″	.97500
11′	.18333	23′	.38333	35′	.58333	47′	.78333	59′	.98333
30″	.19167	30″	.39167	30″	.59167	30″	.79167	30″	.99167
12′	.20000	24′	.40000	36′	.60000	48′	.80000	60′	1.00000

Table VI.—Radii (11)

Degree	Radius	Degree	Radius	Degree	Radius	Degree	Radius
0° 0′	Infinite	9°20′	614.05	18°40′	307.03	28° 0′	204.76
10	34377.50	30	603.29	50	304.31	30	201.17
20	17188.80	40	592.89	19 0	301.64	29 0	197.70
30	11459.20	50	582.85	10	299.02	30	194.36
40	8594.42	10 0	573.14	20	296.45	30 0	191.01
50	6875.55	10	563.75	30	293.91	30	187.88
1 0	5729.65	20	554.66	40	291.42	31 0	184.85
10	4911.15	30	545.87	50	288.98	30	181.91
20	4297.28	40	537.34	20 0	286.57	32 0	179.07
30	3819.83	50	529.08	10	284.20	30	176.32
40	3437.87	11 0	521.07	20	281.87	33 0	173.65
50	3125.36	10	513.30	30	279.58	30	171.06
2 0	2864.93	20	505.76	40	277.33	34 0	168.54
10	2644.58	30	498.43	50	275.11	30	166.10
20	2455.70	40	491.32	21 0	272.94	35 0	163.73
30	2292.01	50	484.40	10	270.78	30	161.42
40	2148.79	12 0	477.68	20	268.67	36 0	159.18
50	2022.41	10	471.15	30	266.59	30	157.00
3 0	1910.08	20	464.78	40	264.54	37 0	154.88
10	1809.57	30	458.59	50	262.52	30	152.82
20	1719.12	40	452.57	22 0	260.54	38 0	150.81
30	1637.28	50	446.69	10	258.58	30	148.85
40	1562.88	13 0	440.97	20	256.65	39 0	146.94
50	1494.95	10	435.40	30	254.75	30	145.08
4 0	1432.69	20	429.96	40	252.88	40 0	143.27
10	1375.40	30	424.66	50	251.04	30	141.50
20	1322.53	40	419.49	23 0	249.22	41 0	139.78
30	1273.57	50	414.44	10	247.43	30	138.09
40	1228.11	14 0	409.32	20	245.66	42 0	136.45
50	1185.78	10	404.51	30	243.92	30	134.84
5 0	1146.28	20	399.80	40	242.20	43 0	133.28
10	1109.33	30	395.21	50	240.51	30	131.75
20	1074.68	40	390.72	24 0	238.84	44 0	130.25
30	1042.14	50	386.33	10	237.20	30	128.79
40	1011.51	15 0	382.04	20	235.57	45 0	127.36
50	982.64	10	377.84	30	233.97	30	125.96
6 0	955.37	20	373.74	40	232.39	46 0	124.59
10	929.57	30	369.72	50	230.83	30	123.25
20	905.13	40	365.79	25 0	229.30	47 0	121.94
30	881.95	50	361.94	10	227.78	30	120.66
40	859.92	16 0	358.17	20	226.28	48 0	119.40
50	838.97	10	354.48	30	224.81	30	118.17
7° 0′	818.64	20	350.86	40	223.35	49 0	116.97
10	799.61	30	347.32	50	221.91	30	115.79
20	781.44	40	343.85	26 0	220.49	50 0	114.63
30	764.08	50	340.45	10	219.08	30	113.49
40	747.48	17 0	337.11	20	217.70	51 0	112.38
50	731.58	10	333.84	30	216.33	30	111.29
8 0	716.34	20	330.63	40	214.98	52 0	110.22
10	701.73	30	327.48	50	213.65	30	109.17
20	687.70	40	324.40	27 0	212.33	53 0	108.14
30	674.22	50	321.37	10	211.03	30	107.13
40	661.26	18 0	318.39	20	209.74	54 0	106.14
50	648.79	10	315.47	30	208.47	30	105.17
9 0	636.78	20	312.61	40	207.22	55 0	104.21
10	625.21	30	309.79	50	205.98	30	103.28

Table VII.—Externals, Radii, Arcs for Tangents of 100 Ft, Deflections

Chord for 50-foot Arc = 50.00

M	Ext Ft	Radius Feet	Diff 10″	Arc Feet	Def Arc 100 Ft	Skew 25 Ft
30	0.2	22918.16		199.999	0° 07.5′	25.00
31		22178.86	119.22		07.8	
32		21485.76	111.92		08.0	
33		20834.67	105.25		08.3	
34		20221.87	99.12		08.5	
35		19644.10	93.52		08.8	
36		19098.41	88.42		09.0	
37		18582.24	[illegible]		09.3	
38		18093.22	79.35		09.5	
39		17629.28	75.32		09.8	
40	0.3	17188.54	71.63	199.998	0° 10.0′	25.00
41		16769.30	68.18		[illegible]	
42		16370.01	64.98		10.5	
43		15989.31	61.97		10.8	
44		15625.90	59.21		11.0	
45		15278.66	56.58		11.3	
46		14946.50	54.15		11.5	
47		14628.48	51.90		11.8	
48		14323.71	49.74		12.0	
49		14031.38	47.73		12.3	
50	0.4	13750.75	45.84	199.996	0° 12.5′	25.00
51		13481.11	44.06		12.8	
52		13221.85	42.38		13.0	
53		12972.37	40.80		13.3	
54		12732.13	39.30		13.5	
55		12500.63	37.88		13.8	
56		12277.39	36.55		14.0	
57		12061.99	35.27		14.3	
58		11854.01	34.07		14.5	
59		11653.09	32.92		14.8	
60	0.4	11458.86	31.83	199.995	0° 15.0′	25.00

Chord for 50-foot Arc = 50.00

M	Ext Ft	Radius Feet	Diff 10″	Arc [illegible]	Def Arc 100 Ft	Skew 25 Ft
0	0.4	11458.86	31.83	[illegible]	0° 15.0′	25.00
1		11271.01	30.80		15.3	
2		11089.20	29.81		15.5	
3		10913.18	28.87		15.8	
4		10742.64	27.98		16.0	
5		10577.37	27.12		16.3	
6		10417.09	26.31		16.5	
7		[illegible]	25.53		16.8	
8		10110.69	24.78		17.0	
9		[illegible]	24.04		17.3	
10	0.5	9821.794	23.39	199.993	0° 17.5′	25.00
11		9683.449	22.73		17.8	
12		9548.947	[illegible]		18.0	
13		9418.130	21.51		18.3	
14		9290.848	20.93		18.5	
15		9166.962	20.37		18.8	
16		9046.333	19.84		19.0	
17		8928.839	19.33		19.3	
18		8814.357	18.84		19.5	
19		8702.774	18.36		19.8	
20	0.6	8593.979	17.91	199.991	0° 20.0′	25.00
21		8487.871	17.47		20.3	
22		8384.350	17.04		20.5	
23		8283.325	16.63		20.8	
24		8184.704	16.24		21.0	
25		8088.404	15.86		21.3	
26		7994.343	15.49		21.5	
27		[illegible]	[illegible]		21.8	
28		7812.634	14.79		22.0	
29		7724.842	14.46		22.3	
30	0.7	7639.000	14.16	199.988	0° 22.5′	25.00
31		7555.046	13.83		22.8	
32		7472.916	13.54		23.0	
33		7392.553	13.25		23.3	
34		7313.899	12.97		23.5	
35		7236.900	12.69		23.8	
36		7161.507	12.43		24.0	
37		7087.667	12.18		24.3	
38		7015.334	11.93		24.5	
39		6944.464	11.69		24.8	
40	0.7	6875.008	11.46	199.986	0° 25.0′	25.00
41		6806.930	11.23		25.3	
42		6740.185	11.01		25.5	
43		6674.737	10.80		25.8	
44		6610.547	10.60		26.0	
45		6547.580	10.39		26.3	
46		[illegible]	10.20		26.5	
47		6425.175	10.01		26.8	
48		6365.674	9.83		27.0	
49		6307.264	9.65		27.3	
50	0.8	6249.915	9.47	199.983	0° 27.5′	25.00
51		6193.600	9.30		27.8	
52		6138.290	9.14		28.0	
53		6083.950	8.98		28.3	
54		6030.582	8.82		28.5	
55		5978.132	8.67		28.8	
56		5926.587	8.52		29.0	
57		5875.923	8.37		29.3	
58		5826.117	8.23		29.5	
59		5777.148	8.09		29.8	
60	0.9	5728.996	7.96	199.980	0° 30.0′	25.00

Table VII.—Externals, Radii, Arcs for Tangents of 100 Ft, Deflections

4°

Chord for 50-foot Arc = 50.00

M	Ext Feet	Radius Feet	Diff 10"	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	1.7	2863.625	1.99	199.919	1° 00.0'	25.02
1		2851.733	1.97	.918	00.3	
2		[redacted]		.917	00.5	
3		2828.243	1.94	.917	00.8	
4		2816.642	1.93	.916	01.0	
5		2805.136	1.91	.916	01.3	
6		2793.723	1.89	.915	01.5	
7		2782.403	1.88	.913	01.8	
8		2771.174	1.86	.913	[redacted]	
9		2760.035	1.85	.912	02.3	
10	[redacted]	2748.985	1.83	199.912	1° 02.5'	25.02
11		2738.024	1.82	.911	02.8	
12		2727 148	1.81	.910	03.0	
13		2716.360	1.79	.910	[redacted]	
14		2705.655	1 78	.909	03.5	
15		2695.035	1.76	[redacted]	03.8	
16		2684.498	1 76	.907	04.0	
17		2674.043	1.74	.907	04.3	
18		2663.669	1 72	.906	[redacted]	
19		2653.375	1.71	.905	04.8	
20	1.9	2643.160	1.70	199.905	1° 05.0'	25.02
21		2633.023	1.68	.904	[redacted]	
22		2622.963	1.67	.903	05.5	
23		2612.981	1.66	.902	05.8	
24		2603.073	1.64	.902	06.0	
25		2593.241	1.63	.901	06.3	
26		2583.482	1.62	.900	06.5	
27		2573.796	1.61	.899	06.8	
28		2564.183	1.60	.899	07.0	
29		2554.641	1.58	.898	07.3	
30	[redacted]	2545.170	1.57	199.897	1° 07.5'	[redacted]
31		2535.768	1.56	.896	07.8	
32		2526.436	1.55	.895	08.0	
33		2517 172	1.54	.895	08.3	
34		2507.975	1.53	.894	08.5	
35		2498.846	1.52	.893	08.8	
36		2480.732	1.51	.892	09.0	
37		2480.784	1.49	.892	[redacted]	
38		2471.851	1.48	.891	09.5	
39		2462.982	1.47	.890	09.8	
40	2.0	2454.175	1.46	199.889	1° 10.0'	25.02
41		2445.433	1 45	.889	10.3	
42		2436.750	1.44	.888	10.5	
43		2428.131	1 43	.887	10.8	
44		2419.571	1.42	.886	11.0	
45		2411.072	1.41	[redacted]	11.3	
46		2402.632	1.40	.885	11.5	
47		2394.251	1.39	[redacted]	11.8	
48		2385.927	1.38	.883	12.0	
49		2377.662	1.37	.882	12.3	
50	2.1	2369 453	1.36	199.881	1° 12.5'	25.02
51		2761.302	1.35	.880	12.8	
52		2353.205	1.36	.880	13.0	
53		2345.164	1.34	.879	13.3	
54		2337.177	1.33	.878	13.5	
55		2329.245	1.32	.877	13.8	
56		2321.366	1.31	.876	14.0	
57		2313.541	1.30	.870	14.3	
58		2305.767	1.29	.875	14.5	
59		2298.047	1.28	.874	14.8	
60	2.2	2290.376	1.27	199.873	1° 15.0'	25.02

5°

0-foot Arc = 50.00

M	Ext Feet	Radius Feet	Diff 10"	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
			27	199.873	1° 15.0'	25.02
			27	.872	15.3	
			26	.871	15.5	
			25	.870	15.8	
			24	.870	16.0	
			23	.869	16.3	
			23	.868	16.6	
			22	.867	16.8	
			21	.866	17.1	
			20	.865	17.3	
			19	199.864	1° 17.6'	25.03
			19	.863	17.8	
			18	.863	18.1	
			17	.862	18.3	
			16	.861	18.5	
			16	.860	18.8	
			15	.859	19.1	
			14	.858	19.3	
			13	.857	19.6	
			13	.856	19.8	
			12	199.856	1° 20.1'	25.03
			11	.855	20.3	
			11	.854	[redacted]	
			10	.853	20.8	
			09	.852	21.1	
			09	.851	21.3	
			08	.850	21.6	
			07	[redacted]	21.8	
			07	.848	22.1	
			06	.847	22.3	
			05	199.846	1° 22.6'	25.03
			05	.845	22.8	
			04	.844	23.1	
			03	.844	23.3	
			03	.843	23.6	
			02	.842	23.8	
			02	.841	24.1	
			01	.840	24.3	
			00	.830	24.6	
			00	.838	24.8	
			99	199.837	1° 25.1'	25.03
			99	.836	25.3	
			98	[redacted]	25.6	
			97	.834	25.8	
			97	.833	26.1	
			96	.832	[redacted]	
			96	[redacted]	26.6	
			95	.830	26.8	
			95	.829	27.1	
			94	.828	27.3	
			94	199.827	1° 27.6'	25.03
			93	.826	27.8	
			92	.825	[redacted]	
			92	.824	28.3	
			91	.823	28.6	
			91	.822	28.8	
			90	.821	29.1	
			90	.820	29.3	
			89	.819	29.6	
			89	.818	29.8	
60	2.6	1908.113	0.88	199.817	1° 30.1'	25.03

for Arcs of 100 Ft, and Skew Distances for Widths of 25 Ft

6°

Chord for 50-foot Arc = 50.00

M	Ext Feet	Radius Feet	Diff 10″	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	2.6	1908.113	.885	199.817	1° 30.1′	25.03
1		1902.818	.880	.816	30.3	
2		1897.552	.875	.815	30.6	
3		1892.315	.870	.814	30.8	
4		1887.106	.866	.813	31.1	
5		1881.927	.861	[illegible]	31.3	
6		1876.775	.856	.811	31.6	
7		1871.662	.852	.810	31.8	
8		1866.556	.847	.809	32.1	
9		1861.488	.842	.808	32.3	
10	2.7	1856.447	.838	199.807	1° 32.6′	25.04
11		1851.434	.833	.806	32.8	
12		1846.447	.829	.805	33.1	
13		1841.487	.824	.804	33.3	
14		1836.553	.820	.803	33.6	
15		1831.647	.816	.802	33.8	
16		1826.765	.811	.800	34.1	
17		1821.915	.807	.799	[illegible]	
18		1817.090	.803	.798	34.6	
19		1812.277	.799	.797	34.8	
20	2.8	1807.497	.794	[illegible].796	1° 35.1′	[illegible]
21		1802.744	.790	.795	35.3	
22		1798.015	.786	.794	[illegible]	
23		1793.311	.782	.793	35.8	
24		1788.631	.778	.792	36.1	
25		1783.975	.774	.791	36.3	
26		1779.344	.770	.790	36.6	
27		1774.737	.766	.789	36.9	
28		1770.152	.762	.788	37.1	
29		1765.593	.758	.786	37.4	
30	2.8	1761.056	.754	199.785	1° 37.6′	25.04
31		1756.542	.750	.784	37.9	
32		1752.051	.747	.783	38.1	
33		1747.584	.743	.782	38.4	
34		1743.138	.739	.781	38.6	
35		1738.716	.735	.780	38.9	
36		1734.316	.732	.779	39.1	
37		1729.937	.728	.778	39.4	
38		1725.580	.724	.776	39.6	
39		1721.247	.721	.775	39.9	
40	2.9	1716.933	.717	199.774	1° 40.1′	25.04
41		1712.643	.713	.773	40.4	
42		1708.372	.710	.772	40.6	
43		1704.124	.706	[illegible]	40.9	
44		1699.895	.703	.770	41.1	
45		1695.689	.699	.769	41.4	
46		1691.502	.696	.767	41.6	
47		1687.337	.692	.766	41.9	
48		1683.191	.689	.765	42.1	
49		1679.068	.686	.764	42.4	
50	3.0	1674.961	.683	199.763	1° 42.6′	25.04
51		1670.876	.679	.762	42.9	
52		1666.811	.676	.760	43.1	
53		1662.766	.672	.759	43.4	
54		1658.739	.669	.758	43.6	
55		1654.733	.666	.757	43.9	
56		1650.745	.663	.756	44.1	
57		1646.777	.660	.755	44.4	
58		1642.827	.657	.754	44.6	
59		1638.897	.653	.752	44.9	
60	3.1	1634.985	.650	199.751	1° 45.1′	25.05

7°

Chord for 50-foot Arc = 50.00

M	Ext Feet	Radius Feet	Diff 10″	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	[illegible]	1634.985	[illegible]	.751	1° 45.1′	25.05
1		1631.092	[illegible]	.750	45.4	
2		1627.217	[illegible]	.749	45.6	
3		[illegible]	[illegible]	.748	45.9	
4		1619.522	[illegible]	.746	46.1	
5		1615.702	[illegible]	.745	46.4	
6		1611.899	[illegible]	.744	[illegible]	
7		1608.115	[illegible]	.743	46.9	
8		1604.348	[illegible]	.741	47.1	
9		1600.599	[illegible]	.740	47.4	
10	3.1	1596.866	[illegible]	.739	1° 47.6′	25.05
11		1593.152	[illegible]	.738	47.9	
12		1589.454	[illegible]	.737	48.1	
13		1585.774	[illegible]	.735	[illegible]	
14		1582.110	[illegible]	.734	48.6	
15		1578.464	[illegible]	[illegible]	48.9	
16		1574.833	[illegible]	[illegible]	49.1	
17		1571.220	.601	.731	49.4	
18		1567.623	.596	.729	49.6	
19		1564.043	.595	[illegible]	49.9	
20	3.2	1560.478	.593	199.727	1° 50.2′	25.05
21		1556.930	.590	[illegible]	50.4	
22		1553.398	.587	.724	50.7	
23		1549.882	.585	.723	50.9	
24		1546.381	.582	.722	51.2	
25		1542.897	.580	.721	51.4	
26		1539.427	.577	.719	51.7	
27		1535.974	.574	.718	51.9	
28		1532.535	.572	.717	52.2	
29		1529.113	.570	.715	52.4	
30	3.3	1525.706	.567	199.714	1° 52.7′	25.05
31		1522.313	.564	.713	52.9	
32		1518.934	.562	.712	[illegible]	
33		1515.572	.559	.710	53.4	
34		1512.224	.557	[illegible]	53.7	
35		1508.891	.554	.708	53.9	
36		1505.572	.552	.707	[illegible]	
37		1502.268	.550	[illegible]	54.4	
38		1498.978	.547	.704	[illegible]	
39		1495.703	.545	.703	54.9	
40	3.3	1492.441	.542	199.702	1° 55.2′	25.06
41		1489.195	.540	.700	55.4	
42		1485.961	.538	.699	55.7	
43		1482.742	.535	.698	55.9	
44		1479.537	[illegible]	.696	56.2	
45		1476.346	.531	.695	56.4	
46		1473.167	.529	.694	56.7	
47		1470.004	.526	.692	[illegible]	
48		1466.852	.524	.691	57.2	
49		1463.716	.522	.690	57.4	
50	3.4	1460.591	.519	199.688	1° 57.7′	25.06
51		1457.491	.517	.687	57.9	
52		1454.383	.515	.686	58.2	
53		1451.299	.513	.684	58.4	
54		1448.227	[illegible]	.683	58.7	
55		1445.169	.509	.682	58.9	
56		1442.123	.506	[illegible]	59.2	
57		1439.090	.504	.679	[illegible]	
58		1436.069	.502	.678	59.7	
59		1433.062	.500	.676	[illegible]	
60	3.5	1430.066	.498	199.675	2° 00.2′	25.06

Table VII.—Externals, Radii, Arcs for Tangents of 100 Ft, Deflections

for Arcs of 100 Ft, and Skew Distances for Widths of 25 Ft

10°

Chord for 50-foot Arc = 50.00

M	Ext Feet	Radius Feet	Diff 10″	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	4.4	1143.006	.319	199.492	2° 30.4′	25.10
1		1141.094	.318	.490	30.6	
2		1139.188	.317	.489	30.9	
3		1137.290	.316	.487	31.1	
4		1135.397	.315	.485	31.4	
5		1133.511	.314	.484	31.6	
6		1131.630	.313	.482	[illegible]	
7		1129.756	.312	.480	32.1	
8		1127.888	.311	.478	32.4	
9		1126.027	.310	.477	32.6	
10	4.4	1124.171	.309	199.475	2° 32.9′	25.10
11		1122.321	.308	.473	33.2	
12		1120.478	.307	.471	33.4	
13		1118.640	.306	.470	33.7	
14		1116.808	.305	.468	33.9	
15		1114.983	.304	[illegible]	34.2	
16		1113.163	.303	.466	34.4	
17		1111.350	.302	.463	34.7	
18		1109.541	.301	.461	[illegible]	
19		1107.739	.300	.459	35.2	
20	4.5	1105.943	.299	199.458	2° 35.4′	25.10
21		1104.153	.298	.456	35.7	
22		1102.367	.297	[illegible]	[illegible]	
23		1100.589	.296	.452	36.2	
24		1098.815	.295	.450	36.4	
25		1097.047	.294	[illegible]	36.7	
26		1095.285	.293	.447	36.9	
27		1093.529	.292	.445	37.2	
28		1091.777	.292	.443	37.4	
29		1090.032	.290	[illegible]	37.7	
30	4.6	1088.292	.290	199.440	2° 37.9′	25.11
31		1086.558	.289	.438	38.2	
32		1084.828	.288	.436	38.4	
33		1083.105	.287	.434	38.7	
34		1081.387	.286	.432	39.0	
35		1079.675	.285	.431	39.2	
36		1077.967	.284	.429	39.5	
37		1076.265	.283	.427	[illegible]	
38		1074.568	.282	.426	40.0	
39		1072.877	.281	[illegible]	40.2	
40	4.7	1071.191	.281	199.423	2° 40.5′	25.11
41		1069.510	.280	.420	40.7	
42		1067.834	.279	.418	41.0	
43		1066.164	.278	.416	41.2	
44		1064.499	.277	[illegible]	41.5	
45		1062.839	.276	.413	41.7	
46		1061.184	.276	.411	42.0	
47		1059.534	.275	.409	42.2	
48		1057.890	.274	.407	42.5	
49		1056.250	.273	[illegible]	[illegible]	
50	4.7	1054.615	.272	199.404	2° 43.0′	25.11
51		1052.985	.271	.402	43.2	
52		1051.360	.270	.400	43.5	
53		1049.741	.270	.398	43.7	
54		1048.126	.269	.396	[illegible]	
55		1046.516	.268	[illegible]	44.2	
56		1044.911	.267	.393	[illegible]	
57		1043.311	.266	.391	[illegible]	
58		1041.716	.266	.389	45.0	
59		1040.126	.265	.387	45.3	
60	4.8	1038.539	.264	199.385	2° 45.5′	25.12

11°

Chord for 50-foot Arc = 49.99

M	Ext Feet	Radius Feet	Diff 10″	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
	.8	1038.539	.264	199.385	2° 45.5′	25.12
		1036.959	.263	.383	45.8	
		1035.382	.262	.382	46.0	
		1033.811	.262	.380	[illegible]	
		1032.244	.261	.378	46.5	
		1030.683	.260	.376	46.8	
		1029.125	.259	[illegible]	[illegible]	
		1027.573	.258	.372	47.3	
		1026.024	.258	[illegible]	47.5	
		1024.481	.257	[illegible]	[illegible]	
	.9	1022.942	.256	199.366	2° 48.0′	25.12
		1021.408	.256	[illegible]	[illegible]	
		1019.878	.255	.363	[illegible]	
		1018.354	.254	.361	48.8	
		1016.833	.253	[illegible]	[illegible]	
		1015.317	.252	.357	49.3	
		1013.806	.252	[illegible]	49.5	
		1012.298	.251	.353	[illegible]	
		1010.796	.250	.351	50.1	
		1009.297	.249	.349	[illegible]	
	[illegible]	1007.803	.249	199.347	2° 50.6′	25.12
		1006.313	.248	.346	50.8	
		1004.828	.247	.344	51.1	
		1003.347	.246	.342	51.3	
		1001.871	.246	.340	51.6	
		1000.398	.245	[illegible]	51.8	
		998.930	.244	.336	52.1	
		997.467	.244	.334	52.3	
		996.007	.243	.332	52.6	
		994.552	.242	.330	52.8	
	.0	993.101	.241	199.328	2° 53.1′	25.13
		[illegible]	.241	[illegible]	53.3	
		990.211	.240	[illegible]	53.6	
		988.773	.239	.322	[illegible]	
		[illegible]	.239	.320	54.1	
		985.908	.238	[illegible]	54.3	
		[illegible]	.237	.316	54.6	
		983.060	.237	[illegible]	[illegible]	
		981.641	.236	[illegible]	55.1	
		980.227	.235	.310	55.4	
	.1	978.817	.235	199.308	2° 55.6′	25.13
		977.411	.234	.306	55.9	
		976.009	.233	.304	56.1	
		974.611	.233	.302	56.4	
		973.217	.232	.300	56.6	
		971.827	.231	.298	56.9	
		970.441	.231	.296	57.1	
		969.058	.230	[illegible]	57.4	
		967.680	.229	[illegible]	57.6	
[illegible]		966.305	.229	.290	57.9	
50	5.2	964.935	.228	199.288	2° 58.1′	25.13
51		963.568	[illegible]	.286	58.4	
52		962.205	.227	.284	58.6	
53		960.846	.227	.282	58.9	
54		959.490	.226	.280	59.1	
55		958.138	.225	.278	59.4	
56		956.791	.224	.276	59.7	
57		955.447	.224	.274	59.9	
58		954.106	.223	.272	3° 00.2′	
[illegible]		952.769	.223	.270	[illegible]	
60	5.2	951.436	.222	199.268	3° 00.7′	[illegible]

Table VII.—Externals, Radii, Arcs for Tangents of 100 Ft, Deflections

M	Ext Feet	Radius Feet	Diff 10″	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
		Chord for 50-foot Arc = 49.99				
0	5.2	951 436	[illegible]	[illegible].268	3° 00.7′	25.14
1		950.107	.221	.266	00.9	
2		948.781	.221	.264	01.2	
3		947.400	.220	.262	01.4	
4		946.141	.219	.260	01.7	
5		944.826	.219	.258	01.9	
6		943.515	.218	.256	[illegible]	
7		942.208	.218	.254	02.4	
8		940.904	.217	.252	02.7	
9		939.603	.216	.250	02.9	
10	5.3	938.307	.216	199.248	3° 03.2′	25.14
11		937.013	.216	.246	03.4	
12		935.724	.215	.244	03.7	
13		934.437	.214	.242	03.9	
14		933.154	.213	.240	04.2	
15		931.875	.213	.238	04.5	
16		930.599	.212	.235	04.7	
17		929.327	.212	.233	05.0	
18		928.058	.211	.231	05.2	
19		926.793	.211	.229	05.5	
20	5.4	925.530	.210	199.227	3° 05.7′	25.15
21		924.272	.209	.225	06.0	
22		923.016	.209	.223	06.2	
23		921.764	.208	.221	06.5	
24		920.516	.208	.219	06.7	
25		919.270	.207	.217	07.0	
26		918.028	.207	.214	07.2	
27		916.790	.206	.212	07.5	
28		915.554	.206	.210	07.7	
29		914.322	.205	.208	08.0	
30	5.5	913.093	.204	199.206	3° 08.2′	25.15
31		911.868	.204	.204	08.5	
32		910.646	.203	.202	08.8	
33		909.426	.203	.200	09.0	
34		908.211	.202	.198	09.3	
35		906.998	.202	.195	09.5	
36		905.789	.201	.193	[illegible]	
37		904.582	.201	.191	10.0	
38		903.379	.200	.189	10.3	
39		902.179	200	.187	10.5	
40	5.5	900 983	.199	199.185	3° 10.8′	25.15
41		899.789	199	.183	11.0	
42		898.598	.198	.180	11.3	
43		897.411	198	.178	11.5	
44		896.227	.197	.176	11.8	
45		895.046	.197	.174	12.0	
46		893.867	196	.172	12.3	
47		892.692	.196	.170	12.5	
48		891.520	195	.167	12.8	
49		890.351	.195	.165	13.1	
50	5.6	889.185	194	199.163	3° 13.3′	25.16
51		888.022	.193	.161	13.6	
52		886.862	.193	159	13.8	
53		885 706	.193	.156	14.1	
54		884.551	192	.154	14.3	
55		883.400	.192	.152	14.6	
56		882.252	.191	.150	14.8	
57		881 107	.191	148	15.1	
58		879.964	190	146	15.3	
59		878.825	190	.143	15.6	
60	5.7	877.689	189	199.141	3° 15.8′	25.16

M	t st.	Radius Feet	Diff 10″	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
		Chord for 50-foot Arc = 49.99				
0	7	87 89	.169	[illegible].141	3° 15.8′	25.16
1		87 58	.189	[illegible]	16.1	
2		87 25	.188	.137	16.3	
3		87 97	.188	.135	16.6	
4		87 72	.187	.132	[illegible]	
5		87 50	127	.130	17.1	
6		87 31	.186	.128	[illegible]	
7		86 14	.186	.126	17.6	
8		86 01	.185	.123	17.9	
9		86 90	185	.121	18.1	
10	8	86 82	.184	199.119	3° 18.4′	25.17
11		86 77	184	.117	18.6	
12		86 75	.183	.114	[illegible]	
13		86...78	.183	.112	19.1	
14		862.078	.183	.110	19.4	
15		860.984	.182	.108	19.6	
16		859.893	.182	.106	19.9	
17		858.804	.181	.103	20.1	
18		857.718	.181	.101	20.4	
19		856.635	.180	[illegible]	20.7	
20	8	855.556	.180	199.097	3° 20.9′	25.17
21		854.477	.179	.094	21.2	
22		853.402	.179	.092	21.4	
23		852.329	.179	.090	21.7	
24		851.259	.178	.087	21.9	
25		850.192	.178	.085	22.2	
26		849.128	.177	[illegible]	22.4	
27		848.066	.177	.081	22.7	
28		847.007	.176	[illegible]	[illegible]	
29		845.950	.176	.076	[illegible]	
30	0	844.896	.175	199.074	3° 23.4′	25.17
31		843.844	.175	.071	23.7	
32		842.796	.175	.069	23.9	
33		841.749	.174	.067	24.2	
34		840.706	.174	.065	24.5	
35		839.664	173	.062	24.7	
36		839.626	173	.060	25.0	
37		837.589	173	.058	25.2	
38		836.556	172	.055	[illegible]	
39		835.524	.172	.053	25.7	
40	0	834.496	.171	199.051	3° 26.0′	25.18
41		833.469	.171	.048	26.2	
42		832.446	170	.046	26.5	
43		831.425	.170	.044	26.7	
44		830.406	.170	.041	27.0	
45		829.390	.169	.039	27.2	
46		828.376	169	.037	27.5	
47		827 364	.168	.034	27.8	
48		826.355	168	.032	28.0	
49		825.349	.167	.030	28.3	
50	0	824.345	167	199.027	3° 28.5′	25.18
51		823.343	167	.025	28.8	
52		822.344	166	.023	29.0	
53		821.347	166	.020	29.3	
54		820 352	166	.018	29.5	
55		819.360	165	.016	29.8	
56		818.370	.165	.013	30.0	
57		817 383	164	.011	30.3	
58		816.398	164	.009	30.5	
59		815.415	.164	[illegible]	30.8	
60	..1	814.435	.163	199.004	3° 31.1′	25.19

for Arcs of 100 Ft, and Skew Distances for Widths of 25 Ft

14° — Chord for 50-foot Arc = 49.99

M	Ext Feet	Radius Feet	Diff 10″	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	6.1	814.435	163	199.004	3° 31.1′	[illegible]
1		813.456	163	.002	31.3	
2		812.481	162	198.999	31.6	
3		811.507	162	198.997	31.8	
4		810.536	.162	.994	32.1	
5		809.567	161	.992	32.3	
6		808.600	161	.989	[illegible]	
7		807.636	.160	.987	32.8	
8		806.674	.160	.985	33.1	
9		805.714	.160	.982	33.3	
10	6.2	804.756	.159	198.980	3° 33.6′	25.19
11		803.801	.159	.978	33.8	
12		802.848	.159	.975	34.1	
13		801.897	.158	.973	34.4	
14		800.948	158	.970	34.6	
15		800.002	.157	.968	34.9	
16		799.058	157	[illegible]	35.1	
17		798.115	.157	.963	35.4	
18		797.176	.156	.961	35.6	
19		796.239	156	.958	35.9	
20	6.3	795.302	156	198.956	3° 36.1′	[illegible]
21		794.369	.155	.953	36.4	
22		793.438	.155	.951	36.6	
23		792.508	.155	.949	36.9	
24		791.582	154	.946	37.1	
25		[illegible]	.154	.944	37.4	
26		789.734	.154	.941	37.7	
27		788.813	.153	.939	37.9	
28		787.895	.153	.936	38.2	
29		786.979	.153	.934	38.4	
30	6.3	786.064	.152	198.931	3° 38.7′	25.20
31		[illegible]	.152	.929	38.9	
32		784.242	.151	.926	39.2	
33		783.334	.151	.924	39.4	
[illegible]		782.429	.151	.921	39.7	
35		781.524	.150	919	39.9	
36		780.622	.150	.917	[illegible]	
37		779.722	150	.914	40.4	
38		778.825	.149	.912	40.7	
39		777.929	149	.909	41.0	
40	6.4	777.035	.149	198.907	3° 41.2′	25.21
41		776.143	.148	.904	41.5	
42		775.254	.148	.902	41.7	
43		774.366	.148	.899	42.0	
44		773.480	.147	.897	42.2	
45		772.597	.147	.894	42.5	
46		771.715	.147	.892	42.7	
47		770.835	.146	.889	43.0	
48		769.957	.146	.887	43.2	
49		769.082	.146	.884	43.5	
50	6.5	768.208	.146	198.882	3° 43.8′	25.21
51		[illegible]	.145	.879	[illegible]	
52		766.466	145	[illegible]	44.3	
53		765.598	.144	[illegible]	[illegible]	
54		764.732	.144	.871	44.8	
55		763.868	.144	.869	45.0	
56		763.005	.143	.866	45.3	
57		762.145	.143	.864	45.5	
58		761.287	.143	.861	45.8	
59		760.430	.143	.859	46.0	
60	6.6	759.575	.142	198.856	3° 46.3′	25.22

15° — Chord for 50-foot Arc = 49.99

M	Ext Feet	Radius Feet	Diff 10″	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	6.6	759.575	.142	1[illegible]6	3° 46.3′	25.22
1		758.723	.142	[illegible]4	[illegible]	
2		[illegible]	.142	[illegible]1	46.8	
3		757.023	.141	[illegible]9	47.1	
4		756.176	.141	[illegible]6	47.3	
5		755.331	.141	[illegible]4	47.6	
6		754.487	140	[illegible]1	47.8	
7		753.646	.140	[illegible]8	48.1	
8		752.806	.140	[illegible]6	48.3	
9		751.968	139	[illegible]3	48.6	
10	6.6	751.132	.139	1[illegible]1	3° 48.8′	25.23
11		750.298	.139	[illegible]8	49.1	
12		749.465	.138	[illegible]5	49.3	
13		748.635	.138	[illegible]3	49.6	
14		747.806	138	[illegible]0	49.9	
15		746.979	.138	[illegible]	50.1	
16		746.154	.137	[illegible]5	50.4	
17		745.330	137	[illegible]3	50.6	
18		744.509	.137	[illegible]0	50.9	
19		743.689	.136	[illegible]7	51.1	
20	6.7	742.871	.136	1[illegible]5	3° 51.4′	25.23
21		742.054	.136	[illegible]2	51.6	
22		741.240	.136	[illegible]0	51.9	
23		740.427	.135	[illegible]7	52.1	
24		739.616	.135	[illegible]4	52.4	
25		738.807	.135	[illegible]2	52.7	
26		737.999	.135	[illegible]9	52.9	
27		737.193	.134	[illegible]7	53.2	
28		736.389	.134	[illegible]4	53.4	
29		735.587	.134	[illegible]1	53.7	
30	[illegible]	734.786	133	1[illegible]9	3° 53.9′	25.23
31		733.987	.133	[illegible]6	54.2	
32		733.190	.133	[illegible]3	54.4	
33		732.394	.133	[illegible]1	54.7	
34		731.600	.132	[illegible]8	[illegible]	
35		730.808	.132	[illegible]6	55.2	
36		730.018	.132	[illegible]3	55.5	
37		[illegible]	131	[illegible]0	55.7	
38		728.442	131	[illegible]8	56.0	
39		727.656	.131	[illegible]5	56.2	
40	6.8	726.873	.131	1[illegible]2	3° 56.5′	25.24
[illegible]		726.090	.130	[illegible]0	56.7	
42		725.310	.130	[illegible]7	57.0	
43		[illegible]	.130	[illegible]4	57.2	
44		723.754	.129	[illegible]2	57.5	
45		722.978	.129	[illegible]9	57.7	
46		722.204	.129	[illegible]6	58.0	
47		721.432	.129	[illegible]4	58.3	
48		720.661	.128	[illegible]1	[illegible]	
49		719.892	.128	[illegible]8	58.8	
50	6.9	719.125	.128	1[illegible]5	3° 59.0′	25.24
51		718.359	.128	[illegible]3	59.3	
52		717.594	.127	[illegible]0	59.5	
53		716.832	127	[illegible]7	59.8	
54		716.071	.127	[illegible]5	4° 00.0′	
55		715.311	.126	[illegible]2	00.3	
56		714.553	126	[illegible]9	00.6	
57		713.797	126	[illegible]7	00.8	
58		713.042	.126	[illegible]4	01.1	
59		712.289	125	[illegible]1	[illegible]	
60	7.0	711.537	.125	1[illegible]9	4° 01.6′	25.25

Table VII.—Externals, Radii, Arcs for Tangents of 100 Ft, Deflections

Chord for 50-foot Arc = [illegible]

M	Ext Feet	Radius Feet	Diff 10"	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	7.0	711.537	.125	198.699	4° 01.6'	25.25
1		[illegible]	.125	.696	01.8	
2		710.038	.125	.693	02.1	
3		709.291	.124	.690	02.3	
4		708.546	.124	.688	02.6	
5		707.802	.124	.685	02.8	
6		707.059	.124	.682	03.1	
7		706.318	.123	.679	03.4	
8		705.579	.123	.677	03.6	
9		704.841	.123	.674	03.9	
10	7.1	704.105	.123	198.671	4° 04.1'	25.25
11		703.370	.122	.668	04.4	
12		702.637	.122	.666	04.6	
13		701.905	.122	.663	[illegible]	
14		701.174	.122	.660	05.1	
15		700.446	.121	.657	05.4	
16		699.718	.121	.655	05.7	
17		698.992	.121	.652	05.9	
18		698.268	.121	.649	06.2	
19		697.545	.120	.646	06.4	
20	7.1	696.823	.120	198.644	4° 06.7'	25.26
21		696.103	.120	.641	06.9	
22		695.385	.120	.638	07.2	
23		694.668	.119	.635	07.4	
24		693.952	.119	.632	07.7	
25		693.238	.119	.630	08.0	
26		692.525	.119	.627	08.2	
27		691.813	.118	.624	[illegible]	
28		[illegible]	.118	.621	08.7	
29		[illegible]	.118	.618	09.0	
30	7.2	689.688	.118	198.616	4° 09.2'	25.26
31		688.982	.117	.613	09.5	
32		688.278	.117	.610	09.7	
33		687.575	.117	.607	10.0	
34		686.874	.117	.604	10.2	
35		686.174	.117	.602	10.5	
36		685.475	.116	[illegible]	10.8	
37		684.778	.116	.596	11.0	
38		684.082	.116	.593	11.3	
39		683.387	.116	.590	11.5	
40	7.3	682.694	.115	198.588	4° 11.8'	25.27
41		682.003	.115	.585	12.0	
42		681.312	.115	.582	12.3	
43		680.623	.115	.579	12.5	
44		679.936	.115	.576	12.8	
45		679.249	.114	[illegible]	13.1	
46		678.564	.114	.571	13.3	
47		677.881	.114	.568	13.6	
48		677.199	.114	.565	13.8	
49		676.518	.114	.562	14.1	
50	7.4	675.838	.113	198.559	4° 14.3'	25.27
51		675.160	.113	.556	14.6	
52		674.483	.113	.553	14.8	
53		673.808	.112	.551	15.1	
54		673.133	.112	.548	15.4	
55		672.460	.112	.545	15.6	
56		671.789	.112	[illegible]	15.9	
57		[illegible]	.112	.539	16.1	
58		670.450	.111	[illegible]	16.4	
59		669.782	.111	.533	16.6	
60	7.4	669.116	.111	198.531	4° 16.9'	25.28

Chord for 50-foot Arc = 49.99

M	Ext Feet	Radius Feet	Diff 10"	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	7.4	669.116	.111	198.531	4° 16.9'	[illegible]
1		668.451	.111	.528	17.1	
2		667.787	.111	.525	17.4	
3		667.124	.110	.522	17.7	
4		666.463	.110	.519	17.9	
5		665.803	.110	.516	18.2	
6		665.144	.110	.513	18.4	
7		664.487	.109	[illegible]	18.7	
8		663.831	.109	.507	18.9	
9		663.176	.109	.504	19.2	
10	7.5	662.523	.109	198.501	4° 19.4'	25.28
11		661.870	.109	.499	19.7	
12		661.219	.108	.496	20.0	
13		660.569	.108	.493	20.2	
14		659.921	.108	.490	20.5	
15		659.273	.108	.487	20.7	
16		658.627	.107	.484	21.0	
17		657.983	.107	.481	21.2	
18		657.339	.107	.478	21.5	
19		656.697	.107	.475	21.7	
20	7.6	656.055	.107	198.472	4° 22.0'	25.29
21		655.415	.107	.469	22.3	
22		654.777	.106	.466	22.5	
23		654.139	.106	.463	22.8	
24		653.503	.106	.460	23.0	
25		652.868	.106	.457	23.3	
26		652.234	[illegible]	.454	23.5	
27		651.601	.105	.452	23.8	
28		650.970	.105	[illegible]	24.0	
29		650.339	.105	[illegible]	24.3	
30	7.7	649.710	.105	198.443	4° 24.6'	25.30
31		649.083	.105	.440	24.8	
32		648.456	.104	.437	25.1	
33		647.830	.104	.434	25.3	
34		647.206	.104	.431	25.6	
35		646.583	.104	.428	25.8	
36		645.961	.104	.425	26.1	
37		645.340	.103	.422	26.4	
38		644.720	.103	.419	26.6	
39		644.102	.103	.416	26.9	
40	7.7	643.484	.103	198.413	4° 27.1'	25.30
41		642.868	.103	.410	27.4	
42		642.253	.102	.407	[illegible]	
43		641.639	.102	.404	27.9	
44		641.026	[illegible]	.401	28.1	
45		640.415	.102	.398	28.4	
46		639.804	.102	[illegible]	28.7	
47		639.196	.101	[illegible]	28.9	
48		638.587	.101	.389	29.2	
49		637.980	.101	.386	29.4	
50	7.8	637.374	.101	198.383	4° 29.7'	25.31
51		636.769	.101	.380	29.9	
52		636.165	.101	.377	30.2	
53		635.562	.100	.374	30.4	
54		634.961	.100	.371	30.7	
55		634.361	.100	.369	31.0	
56		633.761	.100	.364	31.2	
57		633.163	.100	.361	31.5	
58		632.566	.099	.358	31.7	
59		631.970	.099	.355	32.0	
60	7.9	631.375	.099	198.352	4° 32.2'	25.31

for Arcs of 100 Ft, and Skew Distances for Widths of 25 Ft

Chord for 50-foot Arc = 49.99						
M	Ext Feet	Radius Feet	Diff 10"	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	7.9	631.375	.099	198.352	4° 32.2′	25.31
1		630.781	.099	.349	32.5	
2		630.189	.099	.346	32.8	
3		629.597	.098	.343	33.0	
4		629.007	.098	.340	33.3	
5		628.417	.098	[illegible]	33.6	
6		627.829	.098	.334	33.8	
7		627.241	.098	.331	34.0	
8		626.655	.098	.328	34.3	
9		626.070	.097	.325	34.6	
10	7.9	625.486	.097	198.322	4° 34.8′	25.32
11		624.903	.097	.318	35.1	
12		624.321	.097	.315	35.3	
13		623.740	.097	.312	35.6	
14		623.160	.097	.309	35.8	
15		622.581	.096	.306	36.1	
16		622.003	.096	.303	36.3	
17		[illegible]	.096	.300	36.6	
18		620.851	.096	.297	36.9	
19		620.276	.096	.294	37.1	
20	8.0	619.703	.096	198.291	4° 37.4′	25.32
21		619.130	.095	.288	37.6	
22		618.559	.095	.284	37.9	
23		617.988	.095	.281	38.1	
24		617.419	.095	.278	38.4	
25		616.850	.095	.275	38.7	
26		616.283	.095	.272	38.9	
27		615.716	.094	.269	39.2	
28		615.151	.094	.266	39.4	
29		614.586	.094	.262	39.7	
30	8.1	614.023	.094	198.259	4° 39.9′	25.33
31		[illegible]	.094	.256	40.2	
32		612.899	.093	.253	[illegible]	
33		612.339	.093	.250	40.7	
34		611.779	.093	[illegible]	41.0	
35		611.221	.093	.244	41.2	
36		610.664	.093	.240	41.5	
37		610.107	.093	.237	41.7	
38		609.552	.093	.234	42.0	
39		608.997	.092	.231	42.2	
40	8.2	608.444	.092	198.228	4° 42.5′	25.34
41		607.891	.092	.225	42.8	
42		607.340	.092	[illegible]	43.0	
43		606.789	.092	.218	43.3	
44		606.240	.092	.215	43.5	
45		[illegible]	.091	.212	43.8	
46		605.143	.091	.209	44.0	
47		604.597	.091	.206	44.3	
48		604.051	.091	.202	44.6	
49		603.506	.091	.199	[illegible]	
50	8.2	602.962	.091	198.196	4° 45.1′	25.34
51		602.420	.090	[illegible]	45.3	
52		601.878	.090	.189	45.6	
53		601.337	.090	.186	45.8	
54		600.797	.090	[illegible]	[illegible]	
55		600.258	.090	.180	46.4	
56		599.720	.090	.177	46.6	
57		599.182	.090	.173	46.9	
58		598.646	.089	.170	47.1	
59		598.111	.089	.167	47.4	
60	8.3	597.576	.089	198.164	4° 47.6′	25.35

Chord for 50-foot Arc = 49.98						
[illegible]	Ext Feet	Radius [illegible]	Diff 10"	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	[illegible]	597.576	.089	198.164	4° 47.6′	25.35
1		597.043	.089	.161	[illegible]	
2		596.510	.089	.157	[illegible]	
3		595.979	.089	.154	48.4	
4		595.448	.088	.151	48.7	
5		594.918	.088	.148	[illegible]	
6		594.390	[illegible]	.144	49.2	
7		593.862	.088	.141	49.4	
8		593.335	.088	.138	49.7	
9		592.808	.088	.135	50.0	
10	8.4	592.283	.087	198.131	4° 50.2′	25.36
11		591.760	.087	.128	50.5	
12		591.236	.087	[illegible]	50.7	
13		590.713	[illegible]	.122	51.0	
14		590.191	.087	.118	51.2	
15		589.671	.087	.115	51.5	
16		589.151	.087	.112	51.8	
17		588.632	.086	.108	52.0	
18		588.114	.086	[illegible]	52.3	
19		587.597	.086	.102	52.5	
20	8.5	587.080	.086	198.099	4° 52.8′	25.36
21		586.565	.086	.095	53.0	
22		586.051	.086	[illegible]	53.3	
23		585.537	.086	.089	[illegible]	
24		585.024	.085	.085	53.8	
25		584.512	.085	.082	54.1	
26		584.001	.085	.079	54.3	
27		583.491	.085	.076	54.6	
28		582.982	.085	.072	54.8	
29		582.473	.085	.069	55.1	
30	[illegible]	581.966	.085	198.066	4° 55.4′	25.37
31		581.459	.084	.062	55.6	
32		580.953	.084	.059	55.9	
33		580.448	.084	[illegible]	[illegible]	
34		579.944	.084	.052	56.4	
35		579.441	.084	.049	56.6	
36		578.938	.084	.046	56.9	
37		578.437	.084	.042	57.2	
38		577.936	.083	.039	57.4	
39		577.436	.083	.036	57.7	
40	8.6	576.937	.083	198.033	4° 57.9′	25.37
41		576.439	.083	.029	58.2	
42		575.941	.083	.026	58.4	
43		575.445	.083	.022	58.7	
44		[illegible]	.082	[illegible]	59.0	
[illegible]		574.454	.082	.016	59.2	
46		573.960	.082	.012	59.5	
47		573.467	.082	.009	59.7	
48		572.974	.082	[illegible]	5° 00.0′	
49		572.482	.082	.002	00.2	
50	8.7	571.992	.082	197.999	5° 00.5′	25.38
51		571.502	.082	.996	00.8	
52		571.013	.082	.992	01.0	
53		570.524	.081	.989	01.3	
54		570.037	.081	.985	[illegible]	
55		569.550	.081	.982	01.8	
56		569.064	.081	.979	02.1	
57		568.579	.081	975	02.3	
58		568.094	.081	.972	[illegible]	
59		567.611	.081	968	[illegible]	
60	8.7	567.128	.080	197.965	5° 03.1′	25.39

Table VII.—Externals, Radii, Arcs for Tangents of 100 Ft, Deflections

20° — Chord for 50-foot Arc = 49.98

			″	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	8.7	567.128	.080	197.965	5° 03.1′	25.39
1		566.646		.962	03.3	
2		566.165		[illegible]	03.6	
3		565.685		.955	[illegible]	
4		565.205		.951	04.1	
5		564.726		.948	04.4	
6		564.248		.944	04.6	
7		563.771		.941	04.9	
8		563.295		.938	05.1	
9		562.819		.934	05.4	
10	8.8	562.344	.079	197.931	5° 05.7′	25.39
11		561.870		.927	05.9	
12		561.397		.924	06.2	
13		560.924		.920	06.4	
14		560.452		.917	06.7	
15		559.981		.914	07.0	
16		559.511		.910	07.2	
17		559.042		.907	07.5	
18		558.573		.903	07.7	
19		558.105		.900	08.0	
20	8.9	557.638	.078	197.897	5° 08.2′	25.40
21		557.171		.893	08.5	
22		556.706		.890	08.8	
23		556.241		.886	09.0	
24		555.777		.883	09.3	
25		555.313		.879	09.5	
26		554.851		.876	09.8	
27		554.389		.872	10.0	
28		553.927		.869	10.3	
29		553.467		.865	10.6	
30	[illegible]	553.007	.077	197.862	5° 10.8′	25.41
31		552.548		.858	11.1	
32		552.090		.855	11.3	
33		551.633		.851	11.6	
34		551.176		.848	11.9	
35		550.720		.844	12.1	
36		550.264		.841	12.4	
37		549.810		[illegible]	12.6	
38		549.356		.834	12.9	
39		548.903		.830	13.1	
40	9.0	548.451	.075	197.827	5° 13.4′	25.41
41		547.999		.823	13.7	
42		547.548		.820	13.9	
43		547.098		.816	14.2	
44		546.648		.813	14.4	
45		546.199		.809	14.7	
46		545.751		.806	15.0	
47		545.304		.802	15.2	
48		544.857		.799	15.5	
49		544.411		.795	15.7	
50	9.1	543.966	.074	197.791	5° 16.0′	25.42
51		543.521		.788	16.2	
52		543.078		.784	16.5	
53		542.634		.781	16.8	
54		542.192		.777	17.0	
55		541.750		.774	17.3	
56		541.309		.770	17.5	
57		540.869		.767	17.8	
58		540.429		.763	18.1	
59		539.990		.760	18.3	
60	9.2	539.552	.073	197.756	5° 18.6′	25.43

21° — Chord for 50-foot Arc = 49.98

M	Ext Feet	Radius Feet	Diff 10″	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	9.2	539.552	.073	197.756	5° 18.6′	25.43
1		539.114		.752	18.8	
2		538.677		.749	19.1	
3		538.241		.745	19.4	
4		537.805		.742	[illegible]	
5		537.370		[illegible]	19.9	
6		536.936		.734	20.1	
7		536.503		.731	20.4	
8		536.070		.727	20.6	
9		535.638		.724	20.9	
10	9.3	535.206	.072	197.720	5° 21.2′	25.43
11		534.775		.716	21.4	
12		534.345		.713	21.7	
13		533.916		[illegible]	21.9	
14		533.487		.706	22.2	
15		533.059		.702	22.5	
16		532.631		.698	22.7	
17		532.204		.695	23.0	
18		531.778		.691	23.2	
19		[illegible]		.688	23.5	
20	9.3	530.928	.071	197.684	5° 23.7′	[illegible]
21		530.504		.680	24.0	
22		530.080		.677	[illegible]	
23		529.657		.673	24.5	
24		529.235		.669	24.8	
25		528.813		.666	25.0	
26		528.393		.662	25.3	
27		527.972		[illegible]	25.6	
28		527.553		.655	25.8	
29		527.134		.651	26.1	
30	9.4	526.715	.070	[illegible]	5° 26.3′	25.45
31		526.297		.644	26.6	
32		525.880		.640	[illegible]	
33		525.464		.637	27.1	
34		525.048		.633	[illegible]	
35		524.633		.629	27.6	
36		524.218		.626	27.9	
37		523.804		.622	28.2	
38		523.391		.618	28.4	
39		522.978		.615	28.7	
40	9.5	522.566	.069	[illegible]	5° 28.9′	25.45
41		522.155		[illegible]	[illegible]	
42		521.744		.604	29.4	
43		521.334		.600	29.7	
44		520.925		.596	30.0	
45		520.516		.592	30.2	
46		520.107		.589	30.5	
47		519.700		.585	30.7	
48		519.293		.581	31.0	
49		518.886		[illegible]	31.3	
50	9.6	518.480	.068	197.574	5° 31.5′	25.46
51		518.075		.570	31.8	
52		517.671		.566	[illegible]	
53		517.268		.563	32.3	
54		516.863		.559	32.6	
55		516.460		.555	32.8	
56		516.058		.552	33.1	
57		515.657		.548	33.3	
58		515.256		.544	33.6	
59		514.855		.540	33.9	
60	9.6	514.455	.067	197.537	5° 34.1′	25.47

for Arcs of 100 Ft, and Skew Distances for Widths of 25 Ft

22° — Chord of 50-foot Arc = 49.98

M	Ext Feet	Radius Feet	Diff 10"	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	9.6	514.455	.067	197.537	5° 34.1′	25.47
1		514.056		.533	34.4	
2		513.658		.529	34.6	
3		513.260		.525	34.9	
4		512.862		.522	35.2	
5		512.466		.518	35.4	
6		512.069		.514	35.7	
7		511.674		.510	35.9	
8		511.279		.507	36.2	
9		510.884		.503	36.5	
10	9.7	510.490	.066	197.499	5° 36.7′	25.48
11		510.097		.495	37.0	
12		509.704		.491	37.2	
13		509.312		.488	37.5	
14		508.921		.484	37.7	
15		508.530		.480	38.0	
16		508.139		.476	38.3	
17		507.750		.473	38.5	
18		507.360		.469	38.8	
19		506.972		.465	39.0	
20	9.8	506.583	.065	197.461	5° 39.3′	25.48
21		506.196		.457	39.6	
22		505.809		.454	39.8	
23		505.423		.450	40.1	
24		505.037		.446	40.4	
25		504.652		.442	40.6	
26		504.267		.438	40.9	
27		503.883		.435	41.1	
28		503.499		.431	41.4	
29		503.117		.427	41.6	
30	9.8	502.734	.064	197.423	5° 41.9′	25.49
31		502.352		.419	42.2	
32		501.971		.415	42.4	
33		501.590		.412	42.7	
34		501.210		.408	42.9	
35		500.830		.404	43.2	
36		500.451		.400	43.5	
37		500.073		.396	43.7	
38		499.695		.392	44.0	
39		499.317		.389	44.2	
40	9.9	498.940	.063	197.385	5° 44.5′	25.50
41		498.564		.381	44.8	
42		498.188		.377	45.0	
43		497.813		.373	45.3	
44		497.438		.369	45.5	
45		497.064		.365	45.8	
46		496.690		.361	46.1	
47		496.318		.358	46.3	
48		495.945		.354	46.6	
49		495.573		.350	46.8	
50	10.0	495.201	.062	197.346	5° 47.1′	25.50
51		494.831		.342	47.4	
52		494.460		.338	47.6	
53		494.090		.334	47.9	
54		493.721		.330	48.1	
55		493.352		.326	48.4	
56		492.984		.323	48.7	
57		492.616		.319	48.9	
58		492.249		.315	49.2	
59		491.882		.311	49.4	
60	10.1	491.516	.061	197.307	5° 49.7′	25.51

23° — Chord of 50-foot Arc = 49.98

M	Ext Feet	Radius Feet	Diff 10"	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	10.1	491.516	.061	197.307	5° 49.7′	25.51
1		491.150		.303	50.0	
2		490.785		.299	50.2	
3		490.421		.295	50.5	
4		490.056		.291	50.8	
5		489.693		.287	51.0	
6		489.330		.283	51.3	
7		488.967		.279	51.5	
8		488.605		.275	51.8	
9		488.244		.272	52.1	
10	10.1	487.882	.060	197.268	5° 52.3′	25.52
11		487.522		.264	52.6	
12		487.162		.260	52.8	
13		486.803		.256	53.1	
14		486.444		.252	53.4	
15		486.085		.248	53.6	
16		485.727		.244	53.9	
17		485.370		.240	54.1	
18		485.013		.236	54.4	
19		484.657		.232	54.7	
20	10.2	484.300	.059	197.228	5° 54.9′	25.53
21		483.945		.224	55.2	
22		483.590		.220	55.4	
23		483.236		.216	55.7	
24		482.882		.212	56.0	
25		482.529		.208	56.2	
26		482.175		.204	56.5	
27		481.823		.200	56.7	
28		481.471		.196	57.0	
29		481.120		.192	57.3	
30	10.3	480.769	.059	197.188	5° 57.5′	25.54
31		480.418		.184	57.8	
32		480.068		.180	58.0	
33		479.719		.176	58.3	
34		479.370		.172	58.6	
35		479.021		.168	58.8	
36		478.673		.164	59.1	
37		478.326		.160	59.4	
38		477.978		.156	59.6	
39		477.632		.152	59.9	
40	10.4	477.286	.058	197.148	6° 00.1′	25.54
41		476.940		.144	00.4	
42		476.595		.140	00.7	
43		476.250		.136	00.9	
44		475.906		.132	01.2	
45		475.563		.128	01.4	
46		475.219		.124	01.7	
47		474.877		.120	02.0	
48		474.534		.116	02.2	
49		474.192		.112	02.5	
50	10.4	473.851	.057	197.108	6° 02.7′	25.55
51		473.510		.104	03.0	
52		473.170		.100	03.3	
53		472.830		.095	03.5	
54		472.490		.091	03.8	
55		472.151		.087	04.1	
56		471.813		.083	04.3	
57		471.475		.079	04.6	
58		471.137		.075	04.8	
59		470.800		.071	05.1	
60	10.5	470.463	.056	197.067	6° 05.4′	25.56

Table VII.—Externals, Radii, Arcs for Tangents of 100 Ft, Deflections

	24°						25°						
	Chord for 50-foot Arc = 49.98									Chord for 50-foot Arc = [illegible]			
					Def Arc 100 Feet	Skew 25 Ft						Def Arc 100 Feet	Skew 25 Ft
0	10.5	470.463	.066	197.067	6° 05.4′	25.56					7	6° 21.1′	25.6[illegible]
1		470.127		.063	05.6						8	21.3	
2		469.791		.059	05.9						5	21.6	
3		469.456		.055	06.1						4	21.9	
4		469.121		[illegible]	06.4						0	22.1	
5		468.787		[illegible]	06.7						6	22.4	
6		468.452		.042	06.9						1	22.6	
7		468.119		.038	07.2						7	[illegible]	
8		467.786		[illegible]	07.5						2	23.2	
9		467.454		.030	07.7						8	23.4	
10	10.6	467.121	.066	197.026	6° 08.0′	25.57					4	6° 23.7′	25.6[illegible]
11		466.790		.022	08.2						0	24.0	
12		466.458		.018	08.5						5	24.2	
13		466.128		.014	08.8						1	24.5	
14		465.797		[illegible]	09.0						7	24.7	
15		465.466		.005	09.3						2	25.0	
16		465.138		[illegible]	09.5						8	25.3	
17		464.809		196.997	09.8						4	25.5	
18		464.480		.993	10.1		18		445.548		.740	25.8	
19		464.152		[illegible]	10.3		19		445.245		.736	26.1	
20	10.7	463.825	.065	[illegible]	6° 10.6′	25.57	20	11.1	444.942	.050	196.731	6° 26.3′	25.6[illegible]
21		463.498		.961	10.8		21		444.640		.727	26.6	
22		463.171		.976	11.1		22		[illegible]		.722	26.8	
23		462.844		.972	11.4		23		444.036		.718	27.1	
24		462.518		.968	11.6		24		443.735		.714	27.4	
25		462.193		.964	11.9		25		443.434		.709	27.6	
26		461.868		[illegible]	12.2		26		443.134		.705	27.9	
27		461.543		.956	12.4		27		442.834		[illegible]	28.2	
28		461.219		.951	12.7		28		442.534		.696	[illegible]	
29		460.896		.947	12.9		29		442.235		.692	28.7	
30	[illegible]	460.572	.064	196.943	6° 13.2′	25.58	30	11.2	441.936	.050	196.688	6° 28.9′	25.6[illegible]
31		460.249		.939	13.5		31		441.638		.683	29.2	
32		459.927		.935	13.7		32		441.340		.679	29.5	
33		459.605		.931	14.0		33		441.042		.675	29.7	
34		459.283		.926	14.3		34		440.745		[illegible]	30.0	
35		458.962		.922	14.5		35		440.448		.666	30.3	
36		458.041		.918	14.8		36		440.152		.661	30.5	
37		458.321		.914	15.0		37		439.856		.657	30.8	
38		456.001		.910	15.3		38		439.560		.653	31.0	
39		457.682		[illegible]	15.6		39		439.265		.648	31.3	
40	10.8	457.363	.063	196.901	6° 15.8′	25.59	40	11.2	438.969	.049	196.644	6° 31.6′	25.6[illegible]
41		457.044		.897	16.1		41		438.675		.640	[illegible]	
42		456.728		.893	16.4		42		438.381		.635	[illegible]	
43		456.409		.889	16.6		43		438.087		.631	32.4	
44		456.001		.884	16.9		44		437.793		.627	32.6	
45		455.774		.880	17.1		45		437.500		.622	32.9	
46		455.458		.876	17.4		46		437.207		.618	33.1	
47		455.142		.872	17.7		47		[illegible]		.613	33.4	
48		454.826		.868	17.9		48		436.623		.609	33.7	
49		454.511		.863	18.2		49		436.331		.605	33.9	
50	10.9	454.196	.052	196.859	6° 18.4′	25.60	50	11.3	436.040	.049	196.600	6° 34.2′	25.6[illegible]
51		453.882		.855	18.7		51		435.749		.596	34.5	
52		453.568		.851	19.0		52		435.459		.591	34.7	
53		453.254		.846	19.2		53		435.169		.587	35.0	
54		452.941		.842	19.5		54		434.879		.583	35.3	
55		452.629		.838	19.8		55		434.589		.578	35.5	
56		452.316		.834	20.0		56		434.300		.574	35.8	
57		452.004		.829	20.3		57		434.012		.569	36.0	
58		451.693		.825	20.5		58		433.723		.565	36.3	
59		451.382		.821	20.8		59		[illegible]		.561	36.6	
60	11.0	451.071	.052	196.817	6° 21.1′	25.61	60	11.4	433.146	.048	196.556	6° 36.8′	25.6[illegible]

or Arcs of 100 Ft, and Skew Distances for Widths of 25 Ft

Table VII.—Externals, Radii, Arcs for Tangents of 100 Ft, Deflections

28° '

Chord for 50-foot Arc = 49.97

M	Ext Feet	Radius Feet	Diff 10"	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	12.3	401.078	.041	196.004	7° 08.6'	25.77
1		400.830		195.999	08.8	
2		400.582		.994	09.1	
3		400.334		.989	[illegible]	
4		400.086		.984	09.6	
5		399.839		.980	09.9	
6		399.592		.975	10.2	
7		399.346		.970	10.4	
8		399.099		.965	10.7	
9		398.853		.960	11.0	
10	12.3	398.607	.041	195.956	7° 11.2'	25.77
11		398.362		.951	11.5	
12		398.117		.946	11.8	
13		397.872		.941	12.0	
14		397.627		.936	12.3	
15		397.383		.932	12.6	
16		397.139		.927	12.8	
17		396.895		.922	13.1	
18		396.651		.917	13.3	
19		396.408		.912	13.6	
20	12.4	396.165	.041	195.908	7° 13.9'	25.78
21		395.923		.903	14.1	
22		395.680		.898	14.4	
23		395.438		.893	14.7	
24		395.196		.888	14.9	
25		394.955		.883	15.2	
26		[illegible]		.878	15.5	
27		394.472		.874	15.7	
28		394.232		.869	16.0	
29		393.991		.864	16.3	
30	12.5	393.751	.040	195.859	7° 16.5'	[illegible]
31		393.511		.854	16.8	
32		393.271		.849	17.1	
33		393.032		.844	17.3	
34		392.793		.839	17.6	
35		392.554		.835	17.9	
36		[illegible]		.830	18.1	
37		392.077		.825	18.4	
38		391.839		.820	18.7	
39		[illegible]		.815	18.9	
40	12.6	391.364	.040	195.810	7° 19.2'	25.80
41		391.127		.805	19.5	
42		390.890		.800	19.7	
43		390.654		.796	20.0	
44		390.417		.791	20.3	
45		390.181		.786	20.5	
46		389.945		.781	20.8	
47		389.710		.776	21.1	
48		389.474		.771	21.3	
49		389.239		.766	21.6	
50	12.6	389.004	.039	195.761	7° 21.9'	25.81
51		388.770		.756	22.1	
52		388.536		.751	22.4	
53		388.302		.746	22.7	
54		[illegible]		.741	22.9	
55		387.835		.736	23.2	
56		387.601		.732	23.5	
57		387.369		.727	23.7	
58		387.136		.722	[illegible]	
59		386.904		.717	24.3	
60	12.7	386.671	.039	195.712	7° 24.5'	25.82

Chord for 50-foot Arc = 49.97

M	Ext Feet	Radius Feet	Diff 10"	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	12.7	386.671	.039	195.712	7° 24.5'	25.82
1		386.440		[illegible]	24.8	
2		386.208		.702	25.1	
3		385.977		.697	25.3	
4		385.745		.692	25.6	
5		385.515		.687	[illegible]	
6		385.284		.682	26.1	
7		385.054		.677	26.4	
8		384.824		.672	26.7	
9		384.594		.667	26.9	
10	[illegible]	384.364	.038	195.662	7° 27.2'	25.83
11		384.135		.657	27.5	
12		383.906		.652	27.7	
13		383.677		.647	28.0	
14		383.449		.642	28.3	
15		383.220		.637	28.5	
16		382.992		.632	28.8	
17		382.765		[illegible]	29.1	
18		382.537		.622	29.3	
19		382.310		.617	[illegible]	
20	12.9	[illegible]	.038	195.612	7° 29.9'	25.84
21		381.856		.607	30.1	
22		381.630		.602	30.4	
23		381.403		.597	30.7	
24		381.177		.592	30.9	
25		380.952		.587	31.2	
26		380.726		.582	31.5	
27		380.501		.577	31.7	
28		380.276		.572	32.0	
29		380.051		.567	32.3	
30	12.9	379.827	.037	195.562	7° 32.5'	25.85
31		379.602		.557	32.8	
32		379.378		.552	33.1	
33		379.155		.547	33.3	
34		378.931		.542	33.6	
35		378.708		.537	33.9	
36		378.485		.532	[illegible]	
37		378.262		.527	34.4	
38		378.040		.522	34.7	
39		377.817		.517	34.9	
40	13.0	377.595	.037	195.512	7° 35.2'	25.86
41		377.373		.507	35.5	
42		377.152		.501	35.8	
43		376.931		.496	[illegible]	
44		376.709		[illegible]	36.3	
45		376.489		.486	36.6	
46		376.268		.481	36.8	
47		376.048		.476	37.1	
48		375.828		.471	[illegible]	
49		375.608		.466	37.6	
50	13.1	375.388	.037	195.461	7° 37.9'	25.87
51		375.169		.456	38.2	
52		374.950		.450	38.4	
53		374.731		.445	38.7	
54		374.512		.440	39.0	
55		374.294		.435	39.2	
56		[illegible]		.430	39.5	
57		373.858		.425	39.8	
58		373.640		.420	40.0	
59		[illegible]		.415	40.3	
60	[illegible]	373.205	.036	195.410	7° 40.6'	25.88

for Arcs of 100 Ft, and Skew Distances for Widths of 25 Ft

30°

Chord for 50-foot Arc = 49.96

M	Ext Feet				Def Arc 100 Feet	Skew 25 Ft
0	13.2	373.205	.036	195.410	7° 40.6′	[illegible]
1		372.988		[illegible]	[illegible]	
2		372.771		.399	41.1	
3		372.555		.394	41.4	
4		372.338		.389	41.6	
5		372.122		[illegible]	[illegible]	
6		371.907		.379	42.2	
7		371.691		.374	42.4	
8		371.476		.368	42.7	
9		371.261		.363	43.0	
10	13.2	371.046	.036	195.358	7° 43.3′	25.89
11		370.831		.353	43.6	
12		370.616		.348	[illegible]	
13		370.402		.343	44.1	
14		370.188		.338	44.3	
15		369.975		.332	[illegible]	
16		369.761		.327	44.9	
17		369.548		.322	45.1	
18		369.335		.317	45.4	
19		369.122		.312	45.7	
20	13.3	368.909	[illegible]	195.307	7° 45.9′	25.90
21		368.697		.301	46.2	
22		368.485		.296	46.5	
23		368.273		.291	46.7	
24		368.061		.286	47.0	
25		367.850		.281	47.3	
26		367.638		.275	47.6	
27		367.428		.270	47.8	
28		367.217		.265	48.1	
29		367.006		.260	[illegible]	
30	13.4	366.796	.035	195.255	7° 48.6′	25.91
31		366.586		.249	[illegible]	
32		366.376		.244	[illegible]	
33		366.166		.239	49.4	
34		365.957		.234	49.7	
35		365.748		.228	50.0	
36		365.539		.223	50.2	
37		365.330		.218	[illegible]	
38		365.121		.213	50.8	
39		364.913		.208	51.0	
40	13.5	364.705	.035	195.202	7° 51.3′	25.92
41		364.497		.197	51.6	
42		364.289		[illegible]	51.8	
43		364.080		[illegible]	52.1	
44		363.874		[illegible]	52.4	
45		363.663		.176	52.7	
46		363.461		.171	52.9	
47		363.254		[illegible]	[illegible]	
48		363.048		.160	53.5	
49		362.842		.155	53.7	
50	13.5	362.636	.034	195.150	7° 54.0′	25.93
51		362.430		.144	[illegible]	
52		362.224		.139	[illegible]	
53		362.019		.134	[illegible]	
54		361.814		.129	55.1	
55		361.609		.123	55.3	
56		361.405		.118	55.6	
57		361.200		[illegible]	55.9	
58		360.996		[illegible]	56.2	
59		360.792		.102	56.4	
60	13.6	[illegible]	.034	195.097	7° 56.7′	25.94

31°

Chord for 50-foot Arc = 49.96

M	Ext Feet	Radius Feet	Diff 10″			
0	[illegible]	360.588	.034	195.097	7° 56.7′	25.94
1		360.386		.092	57.0	
2		360.181		.086	57.2	
3		[illegible]		[illegible]	57.5	
4		359.776		.076	57.8	
5		359.573		.070	58.0	
6		359.370		.065	58.3	
7		359.168		.060	58.6	
8		358.966		.054	58.8	
9		358.764		.049	59.1	
10	13.7	358.562	.034	195.044	7° 59.4	25.96
11		358.361		.038	59.6	
12		358.160		.033	59.9	
13		357.959		.028	8° 00.2′	
14		357.758		.022	00.5	
15		357.557		.017	00.7	
16		357.357		.012	01.0	
17		357.157		.006	01.3	
18		356.957		.001	01.5	
19		356.757		194.996	01.8	
20	13.8	356.557	.033	194.990	8° 02.1′	25.96
21		356.358		.985	02.3	
22		356.159		[illegible]	02.6	
23		355.960		.974	02.9	
24		355.761		.969	03.2	
25		355.563		[illegible]	03.4	
26		355.364		.958	03.7	
27		355.166		.953	04.0	
28		354.968		.947	04.2	
29		354.771		.942	04.5	
30	13.8	354.573	.033	194.937	8° 04.8′	25.98
31		354.376		[illegible]	05.0	
32		354.179		.926	05.3	
33		353.982		[illegible]	05.6	
34		353.785		.915	05.9	
35		353.589		.910	06.1	
36		353.393		.904	06.4	
37		[illegible]		.899	06.7	
38		353.001		.894	06.9	
39		352.805		.888	07.2	
40	13.9	352.609	.033	194.883	8° 07.5′	25.99
41		352.414		.877	07.7	
42		352.219		.872	08.0	
43		352.024		.866	08.3	
44		351.829		.861	08.6	
[illegible]		351.635		.856	08.8	
46		351.441		.850	09.1	
47		351.247		.845	09.4	
48		351.053		[illegible]	09.6	
49		350.859		.834	09.9	
50	14.0	350.666	.032	[illegible]	8° 10.2′	26.00
51		350.472		.823	10.4	
52		350.279		.817	10.7	
53		350.086		.812	11.0	
54		349.894		.807	11.3	
55		349.701		.801	11.5	
56		349.509		[illegible]	11.8	
57		349.317		.790	12.1	
58		349.125		.785	[illegible]	
59		348.933		.779	12.6	
60	14.1	348.741	.032	194.774	8° 12.9′	26.01

Table VII.—Externals, Radii, Arcs for Tangents of 100 Ft, Deflections

			32°			
			Chord for 50-foot Arc = 49.96			
M	Ext Feet	Radius Feet	Diff 10″	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	14.1	[illegible]	.032	194.774	8° 12.9′	26.01
1		348.550		.768	13.1	
2		348.359		.763	13.4	
3		348.168		.757	13.7	
4		347.977		.752	14.0	
5		347.787		.746	14.2	
6		347.596		.741	14.5	
7		347.406		.735	14.8	
8		347.216		.730	15.0	
9		347.026		.724	15.3	
10	14.1	346.837	.032	194.719	8° 15.6′	26.02
11		346.647		.713	15.9	
12		346.458		.708	16.1	
13		346.269		.702	16.4	
14		346.080		.697	16.7	
15		345.892		[illegible]	16.9	
16		345.703		.686	17.2	
17		345.515		.680	17.5	
18		345.327		.675	17.8	
19		345.139		.669	18.0	
20	14.2	344.951	.031	194.664	8° 18.3′	26.03
21		344.764		.658	18.6	
22		344.576		653	18.8	
23		344.389		.647	19.1	
24		344.202		.642	19.4	
25		344.016		[illegible]	19.7	
26		343.829		.631	19.9	
27		343.643		.625	20.2	
28		343.456		.619	20.5	
29		343.270		.614	20.7	
30	14.3	[illegible]	.031	194.608	8° 21.0′	26.04
31		342.899		.603	[illegible]	
32		342.713		.597	21.5	
33		342.528		[illegible]	21.8	
34		342.343		.586	22.1	
35		342.158		.581	[illegible]	
36		341.973		.575	22.6	
37		341.789		.569	[illegible]	
38		341.604		.564	23.2	
39		341.420		.558	[illegible]	
40	14.4	341.236	.031	194.553	8° 23.7′	26.05
41		341.053		.547	24.0	
42		340.869		[illegible]	24.3	
43		340.685		.536	24.5	
44		340.502		.530	24.8	
45		340.319		.525	25.1	
46		340.136		.519	25.3	
47		239.953		.513	25.6	
48		339.771		.508	25.9	
49		339.589		.502	26.2	
50	14.4	[illegible]	.030	194.497	8° 26.4′	26.06
51		339.224		.491	26.7	
52		[illegible]		[illegible]	27.0	
53		338.861		.480	[illegible]	
54		338.679		[illegible]	27.5	
55		338.498		.468	27.8	
56		338.317		[illegible]	28.1	
57		338.136		.457	28.3	
58		337.955		.452	28.6	
59		337.775		.446	28.9	
60	14.5	337.594	.030	[illegible]	8° 29.2′	26.07

			33°			
			Chord for 50-foot Arc = 49.96			
M	E F					
0	14.5	337.594	[illegible]	[illegible]	8° 29.2′	26.07
1		337.414		.435	29.4	
2		337.234		.429	29.7	
3		337.054		.423	30.0	
4		336.875		.418	30.2	
5		336.695		.412	30.5	
6		336.516		.406	30.8	
7		336.337		.401	31.1	
8		336.158		.395	31.3	
9		335.979		.389	31.6	
10	14.6	335.800	.030	194.384	8° 31.9′	26.09
11		335.622		.378	32.1	
12		335.443		.372	32.4	
13		335.265		.367	32.7	
14		335.087		.361	33.0	
15		334.910		.355	[illegible]	
16		334.732		.350	33.5	
17		334.555		.344	33.8	
18		334.377		.338	34.1	
19		334.200		.332	34.3	
20	14.6	334.023	.029	194.327	8° 34.6′	26.10
21		333.847		.321	34.9	
22		333.670		.315	35.1	
23		333.[illegible]		.310	35.4	
24		333.317		[illegible]	35.7	
25		333.141		.298	36.0	
26		332.965		.292	36.2	
27		332.790		.287	[illegible]	
28		332.614		.281	36.8	
29		332.439		[illegible]	37.1	
30	14.7	332.264	.029	194.270	8° 37.3′	[illegible]
31		332.089		.264	37.6	
32		331.914		.258	37.9	
33		331.739		.252	38.1	
34		331.565		.247	38.4	
35		331.390		.241	38.7	
36		331.216		.235	39.0	
37		331.042		.229	39.2	
38		330.868		.224	39.5	
39		330.695		.218	39.8	
40	14.8	330.521	.029	194.212	8° 40.1′	26.12
41		330.348		.206	40.3	
42		330.174		.201	40.6	
43		330.001		.195	40.9	
44		329.829		189	41.1	
45		329.656		183	41.4	
46		329.483		.177	41.7	
47		329.311		.172	42.0	
48		[illegible].139		.166	42.2	
49		328.967		160	42.5	
50	14.9	328.795	029	194.154	8° 42.8′	26.13
51		328.623		.148	43.1	
52		328.452		.143	43.3	
53		328.280		.137	43.6	
54		328.109		.131	43.9	
55		327.938		.125	44.1	
56		327.767		.119	44.4	
57		327.596		.114	44.7	
58		327.426		.108	45.0	
59		327.256		.102	45.2	
60	14.9	327.085	.028	194.096	8° 45.5′	26.14

for Arcs of 100 Ft, and Skew Distances for Widths of 25 Ft

Chord for 50-foot Arc = 49.96						
M	Ext Feet	Radius Feet	Diff 10"	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	14.9	327.085	.028	194.096	8° 45.5'	26.14
1		326.915		.090	45.8	
2		326.745		.085	[illegible]	
3		326.576		.079	46.3	
4		326.406		.073	46.6	
5		326.237		.067	[illegible]	
6		326.067		.061	47.2	
7		325.898		.056	47.4	
8		325.729		.049	47.7	
9		325.561		.044	48.0	
10	15.0	325.392	.028	194.038	8° 48.2'	26.15
11		325.223		.032	48.5	
12		325.055		.026	48.8	
13		324.887		.020	49.1	
14		324.719		.014	[illegible]	
15		324.551		.008	49.6	
16		324.383		.003	49.9	
17		324.216		193.997	50.2	
18		324.049		.991	50.4	
19		323.881		.985	50.7	
20	15.1	323.714	[illegible]	193.979	8° 51.0'	26.17
21		323.548		.973	51.3	
22		323.381		.967	51.5	
23		323.214		.961	51.8	
24		323.048		.956	52.1	
25		322.882		.950	52.4	
26		322.715		.944	52.6	
27		322.550		.938	52.9	
28		322.384		.932	53.2	
29		322.218		.926	53.5	
30	15.2	322.053	.028	193.920	8° 53.7'	26.18
31		321.887		.914	54.0	
32		321.722		.908	54.3	
33		321.557		.902	54.5	
34		321.392		.897	54.8	
35		321.228		.891	55.1	
36		321.063		.885	55.4	
37		320.899		.879	55.6	
38		320.734		.873	55.9	
39		320.570		.867	56.2	
40	15.2	320.406	.027	193.861	8° 56.5'	26.19
[illegible]		320.243		.855	56.7	
42		320.079		.849	57.0	
43		319.916		.843	57.3	
44		319.752		.837	57.6	
45		319.589		.831	57.8	
46		319.426		.825	[illegible]	
47		319.263		[illegible]	58.4	
48		[illegible]		.813	58.7	
49		318.938		.807	58.9	
50	15.3	318.775	.027	193.801	8° 59.2'	26.20
51		318.613		.795	59.5	
52		318.451		.789	59.8	
53		318.289		.783	9° 00.0'	
54		318.127		.778	00.3	
55		317.966		.772	00.6	
56		317.804		.766	00.9	
57		317.643		.760	01.1	
[illegible]		317.481		.754	01.4	
59		317.320		.748	01.7	
60	15.4	317.159	.027	193.742	9° 02.0'	26.21

Chord for 50-foot Arc = 49.96						
M	Ext Feet	Radius Feet	Diff 10"	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	15.4	[illegible]	.027	193.742	9° 02.0'	26.21
1		316.999		.736	02.2	
2		316.838		.730	02.5	
3		316.678		[illegible]	[illegible]	
4		316.517		.718	03.1	
5		316.357		.712	[illegible]	
6		316.197		[illegible]	03.6	
7		316.037		.700	03.9	
8		315.877		.694	04.2	
9		315.718		.687	04.4	
10	15.5	315.558	.027	193.681	9° 04.7'	26.23
11		315.399		.675	05.0	
12		315.240		.669	05.3	
13		315.081		.663	05.5	
14		314.922		.657	05.8	
15		314.763		[illegible]	06.1	
16		314.605		.645	06.4	
17		314.446		.639	06.6	
18		314.288		[illegible]	06.9	
19		314.130		.627	07.2	
20	15.5	313.972	.026	193.621	9° 07.5'	26.24
21		313.814		.615	07.7	
22		313.656		[illegible]	08.0	
23		313.499		.603	08.3	
24		313.341		.597	08.6	
25		313.184		.591	08.8	
26		313.027		.585	09.1	
27		312.870		.579	09.4	
28		312.713		.572	09.7	
29		312.557		.566	[illegible]	
30	15.6	312.400	.026	193.560	9° 10.2'	26.25
31		312.244		.554	10.5	
32		312.087		.548	10.8	
33		311.931		.542	11.0	
34		311.775		.536	11.3	
35		311.619		.530	11.6	
36		311.464		.524	11.9	
37		311.308		[illegible]	12.1	
38		311.153		.512	12.4	
39		310.997		.505	12.7	
40	15.7	310.842	.026	193.499	9° 13.0'	26.26
41		310.687		.493	13.2	
42		310.532		.487	13.5	
43		310.378		.481	13.8	
44		310.223		.475	14.1	
45		310.069		[illegible]	14.4	
46		309.914		.463	14.6	
47		309.760		.456	14.9	
48		309.606		.450	15.2	
49		309.452		.444	[illegible]	
50	15.8	[illegible]	.026	193.438	9° 15.7'	26.27
51		309.146		.432	16.0	
52		308.991		.426	16.3	
53		308.838		.420	16.6	
54		308.685		.413	16.8	
55		308.532		.407	17.1	
56		308.379		.401	17.4	
57		308.226		.395	17.7	
58		308.073		.389	17.9	
59		307.921		.383	[illegible]	
60	15.8	307.768	.025	193.377	9° 18.5'	26.29

Table VII.—Externals, Radii, Arcs for Tangents of 100 Ft, Deflections

36°						
Chord for 50-foot Arc = 49.95						
M	Ext Feet	Radius Feet	Diff 10″	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	15.8	307.768	.025	193.377	9° 18.5′	26.29
1		307.616		.370	18.8	
2		307.464		.364	19.0	
3		307.312		.358	19.3	
4		307.160		.352	19.6	
5		307.009		.346	19.9	
6		306.857		.339	20.2	
7		306.706		.333	20.4	
8		306.554		.327	20.7	
9		306.403		.321	21.0	
10	15.9	306.252	.025	193.315	9° 21.3′	26.30
11		306.101		.308	21.5	
12		305.950		.302	21.8	
13		305.800		.296	22.1	
14		305.649		.290	22.4	
15		305.499		.284	22.6	
16		305.349		.277	22.9	
17		305.199		.271	23.2	
18		305.049		.265	23.5	
19		304.899		.259	23.8	
20	16.0	304.749	.025	193.253	9° 24.0′	26.31
21		304.600		.246	24.3	
22		304.450		.240	24.6	
23		304.301		.234	24.9	
24		304.152		.227	25.1	
25		304.003		.221	25.4	
26		303.854		.215	25.7	
27		303.705		.209	26.0	
28		303.556		.202	26.2	
29		303.408		.196	26.5	
30	16.1	303.260	.025	193.190	9° 26.8′	26.32
31		303.111		.184	27.1	
32		302.963		.177	27.4	
33		302.815		.171	27.6	
34		302.667		.165	27.9	
35		302.520		.159	28.2	
36		302.372		.152	28.5	
37		302.225		.146	28.7	
38		302.077		.140	29.0	
39		301.930		.134	29.3	
40	16.1	301.783	.025	193.127	9° 29.6′	26.34
41		301.636		.121	29.8	
42		301.489		.115	30.1	
43		301.343		.108	30.4	
44		301.196		.102	30.7	
45		301.050		.096	31.0	
46		300.903		.089	31.2	
47		300.757		.083	31.5	
48		300.611		.077	31.8	
49		300.465		.070	32.1	
50	16.2	300.319	.024	193.064	9° 32.4′	26.35
51		300.174		.058	32.6	
52		300.028		.051	32.9	
53		299.883		.045	33.2	
54		299.738		.039	33.5	
55		299.592		.032	33.7	
56		299.447		.026	34.0	
57		299.302		.020	34.3	
58		299.158		.013	34.6	
59		299.013		.007	34.8	
60	16.3	298.869	.024	193.001	9° 35.1′	26.36

37°						
Chord for 50-foot Arc = 49.94						
M	Ext Feet	Radius Feet	Diff 10″	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	16.3	298.869	.024	193.001	9° 35.1′	26.36
1		298.724		192.994	35.4	
2		298.580		.988	35.7	
3		298.436		.982	36.0	
4		298.292		.975	36.2	
5		298.148		.969	36.5	
6		298.004		.963	36.8	
7		297.860		.956	37.1	
8		297.717		.950	37.4	
9		297.573		.943	37.6	
10	16.4	297.430	.024	192.937	9° 37.9′	26.38
11		297.287		.931	38.2	
12		297.144		.924	38.5	
13		297.001		.918	38.7	
14		296.858		.911	39.0	
15		296.716		.905	39.3	
16		296.573		.899	39.6	
17		296.431		.892	39.9	
18		296.288		.886	40.1	
19		296.146		.880	40.4	
20	16.4	296.004	.024	192.873	9° 40.7′	26.39
21		295.862		.867	41.0	
22		295.721		.860	41.2	
23		295.579		.854	41.5	
24		295.437		.847	41.8	
25		295.296		.841	42.1	
26		295.155		.835	42.4	
27		295.013		.828	42.6	
28		294.872		.822	42.9	
29		294.731		.815	43.2	
30	16.5	294.591	.023	192.809	9° 43.5′	26.40
31		294.450		.802	43.8	
32		294.309		.796	44.0	
33		294.169		.789	44.3	
34		294.028		.783	44.6	
35		293.888		.777	44.9	
36		293.748		.770	45.2	
37		293.608		.764	45.4	
38		293.468		.757	45.7	
39		293.329		.751	46.0	
40	16.6	293.189	.023	192.744	9° 46.3′	26.41
41		293.049		.738	46.5	
42		292.910		.731	46.8	
43		292.771		.725	47.1	
44		292.632		.718	47.4	
45		292.493		.712	47.7	
46		292.354		.705	47.9	
47		292.215		.699	48.2	
48		292.076		.692	48.5	
49		291.938		.686	48.8	
50	16.7	291.799	.023	192.679	9° 49.1′	26.43
51		291.661		.673	49.3	
52		291.523		.666	49.6	
53		291.384		.660	49.9	
54		291.246		.653	50.1	
55		291.109		.647	50.5	
56		290.971		.640	50.7	
57		290.833		.634	51.0	
58		290.696		.627	51.3	
59		290.558		.621	51.6	
60	16.7	290.421	.023	192.615	9° 51.9′	26.44

for Arcs of 100 Ft, and Skew Distances for Widths of 25 Ft

38°						
Chord for 50-foot Arc = 49.94						
M	Ext Feet	Radius Feet	Diff 10″	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	16.7	290.421	.023	192.615	9° 51.9′	26.44
1		290.284		.608	52.1	
2		290.147		.601	52.4	
3		290.010		.595	52.7	
4		289.873		.588	53.0	
5		289.736		.582	53.3	
6		289.600		.575	53.5	
7		289.463		.569	53.8	
8		289.327		.562	54.1	
9		289.191		.556	54.4	
10	16.8	289.055	.023	192.549	9° 54.7′	26.45
11		288.919		.542	54.9	
12		288.783		.536	55.2	
13		288.647		.529	55.5	
14		288.511		.523	55.8	
15		288.376		.516	56.1	
16		288.240		.510	56.3	
17		288.105		.503	56.6	
18		287.970		.497	56.9	
19		287.835		.490	57.2	
20	16.9	287.700	.023	192.483	9° 57.5′	26.47
21		287.565		477	57.7	
22		297.430		.470	58.0	
23		287.295		.464	58.3	
24		287.161		.457	58.6	
25		287.026		.450	58.9	
26		286.892		.444	59.1	
27		286.758		.437	59.4	
28		286.624		.431	59.7	
29		286.490		.424	10° 00.0′	
30	17.0	286.356	.022	192.417	10° 00.3′	26.48
31		286.222		.411	00.5	
32		286.089		.404	00.8	
33		285.955		.397	01.1	
34		285.822		.391	01.4	
35		285.688		.384	01.7	
36		285.555		.378	01.9	
37		285.422		.371	02.2	
38		285.289		.364	02.5	
39		235.156		.358	02.8	
40	17.0	285.023	.022	192.351	10° 03.1′	26.49
41		284.891		.345	03.3	
42		284.758		.338	03.6	
43		284.626		.331	03.9	
44		284.494		.324	04.2	
45		284.361		.318	04.5	
46		284.229		.311	04.7	
47		284.097		.304	05.0	
48		283.965		.298	05.3	
49		283.834		.291	05.6	
50	17.1	283.702	.022	192.284	10° 05.9′	26.51
51		283.570		.278	06.2	
52		283.439		.271	06.4	
53		283.308		.264	06.7	
54		283.176		.258	07.0	
55		283.045		.251	07.3	
56		282.914		.244	07.6	
57		282.783		.238	07.8	
58		282.653		.231	08.1	
59		282.522		.224	08.4	
60	17.2	282.391	.022	192.218	10° 08.7′	26.52

39°						
Chord for 50-foot Arc = 49.93						
M	Ext Feet	Radius Feet	Diff 10″	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	17.2	282.391	.022	192.218	10° 08.7′	26.52
1		282.261		.211	09.0	
2		282.130		.204	09.2	
3		282.000		.197	09.5	
4		281.870		.191	09.8	
5		281.740		.184	10.1	
6		281.610		.177	10.4	
7		281.480		.171	10.7	
8		281.350		.164	10.9	
9		281.221		.157	11.2	
10	17.3	281.091	.022	192.150	10° 11.5′	26.53
11		280.962		.144	11.8	
12		280.833		.137	12.1	
13		280.703		.130	12.3	
14		280.574		.123	12.6	
15		280.445		.117	12.9	
16		280.316		.110	13.2	
17		280.188		.103	13.5	
18		280.059		.096	13.8	
19		279.930		.090	14.0	
20	17.3	279.802	.021	192.083	10° 14.3′	26.55
21		279.674		.076	14.6	
22		279.545		.069	14.9	
23		279.417		.063	15.2	
24		279.289		.056	15.4	
25		279.161		.049	15.7	
26		279.033		.042	16.0	
27		278.906		.035	16.3	
28		278.778		.029	16.6	
29		278.651		.022	16.9	
30	17.4	278.523	.021	192.015	10° 17.1′	26.56
31		278.396		.008	17.4	
32		278.269		.002	17.7	
33		278.141		191.995	18.0	
34		278.014		.988	18.3	
35		277.888		.981	18.6	
36		277.761		.974	18.8	
37		277.634		.968	19.1	
38		277.507		.961	19.4	
39		277.381		.954	19.7	
40	17.5	277.254	.021	191.947	10° 20.0′	26.58
41		277.128		.940	20.2	
42		277.002		.933	20.5	
43		276.876		.927	20.8	
44		276.750		.920	21.1	
45		276.624		.913	21.4	
46		276.498		.906	21.7	
47		276.373		.899	21.9	
48		276.247		.802	22.2	
49		276.121		.886	22.5	
50	17.6	275.996	.021	191.879	10° 22.8′	26.59
51		275.871		.872	23.1	
52		275.746		.865	23.4	
53		275.621		.858	23.6	
54		275.496		.851	23.9	
55		275.371		.844	24.2	
56		275.246		.838	24.5	
57		275.121		.831	24.8	
58		274.997		.824	25.1	
59		274.872		.817	25.3	
60	17.6	274.748	.021	191.810	10° 25.6′	26.60

Table VII.—Externals, Radii, Arcs for Tangents of 100 Ft, Deflections

40°							41°						
Chord for 50-foot Arc = 49.93							Chord for 50-foot Arc = 49.93						
					Def Arc 100 Feet	Skew 25 Ft	M	Ext Feet	Radius Feet	Diff 10"	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	17.6	274.748	.021	191.810	10° 25.6'	26.60	0	18.1	267.462	.020	191.392	10° 42.7'	26.69
1		274.623		.803	25.9	26.61	1		267.344		.385	42.9	26.69
2		274.499		.796	26.2	26.61	2		267.225		.378	43.2	26.69
3		274.375		.789	26.5	26.61	3		267.107		.371	43.5	26.69
4		274.251		.782	26.8	26.61	4		266.989		.364	43.8	26.70
5		274.127		.776	27.0	26.61	5		266.870		.356	44.1	26.70
6		274.004		.769	27.3	26.61	6		266.752		.349	44.4	26.70
7		273.880		.762	27.6	26.61	7		266.634		.342	44.7	26.70
8		273.756		.755	27.9	26.62	8		266.516		.335	44.9	26.70
9		273.633		.748	28.2	26.62	9		266.399		.328	45.2	26.70
10	17.7	273.509	.021	191.741	10° 28.5'	26.62	10	18.2	266.281	.020	191.321	10° 45.5'	26.70
11		273.386		.734	28.7	26.62	11		266.163		.314	45.8	26.71
12		273.263		.727	29.0	26.62	12		266.046		.307	46.1	26.71
13		273.140		.720	29.3	26.62	13		265.928		.300	46.4	26.71
14		273.017		.713	29.6	26.62	14		265.811		.293	46.7	26.71
15		272.894		.706	29.9	26.63	15		265.694		.286	46.9	26.71
16		272.771		.700	30.2	26.63	16		265.576		.278	47.2	26.71
17		272.648		.693	30.4	26.63	17		265.459		.271	47.5	26.72
18		272.526		.686	30.7	26.63	18		265.342		.264	47.8	26.72
19		272.403		.679	31.0	26.63	19		265.225		.257	48.1	26.72
20	17.8	272.281	.020	191.672	10° 31.3'	26.63	20	18.2	265.109	.019	191.250	10° 48.4'	26.72
21		272.158		.665	31.6	26.63	21		264.992		.243	48.7	26.72
22		272.036		.658	31.9	26.64	22		264.875		.236	48.9	26.72
23		271.914		.651	32.1	26.64	23		264.759		.229	49.2	26.72
24		271.792		.644	32.4	26.64	24		264.642		.222	49.5	26.73
25		271.670		.637	32.7	26.64	25		264.526		.214	49.8	26.73
26		271.548		.630	33.0	26.64	26		264.410		.207	50.1	26.73
27		271.427		.623	33.3	26.64	27		264.294		.200	50.4	26.73
28		271.305		.616	33.6	26.64	28		264.177		.193	50.7	26.73
29		271.183		.609	33.8	26.65	29		264.061		.186	50.9	26.73
30	17.9	271.062	.020	191.602	10° 34.1'	26.65	30	18.3	263.945	.019	191.179	10° 51.2'	26.73
31		270.941		.595	34.4	26.65	31		263.830		.171	51.5	26.74
32		270.819		.588	34.7	26.65	32		263.714		.164	51.8	26.74
33		270.698		.581	35.0	26.65	33		263.598		.157	52.1	26.74
34		270.577		.574	35.3	26.65	34		263.483		.150	52.4	26.74
35		270.456		.567	35.5	26.65	35		263.367		.143	52.7	26.74
36		270.335		.560	35.8	26.66	36		263.252		.136	52.9	26.74
37		270.214		.553	36.1	26.66	37		263.137		.129	53.2	26.74
38		270.094		.546	36.4	26.66	38		263.021		.121	53.5	26.75
39		269.973		.539	36.7	26.66	39		262.906		.114	53.8	26.75
40	17.9	269.853	.020	191.532	10° 37.0'	26.66	40	18.4	262.791	.019	191.107	10° 54.1'	26.75
41		269.732		.525	37.3	26.66	41		262.676		.100	54.4	26.75
42		269.612		.518	37.5	26.66	42		262.561		.093	54.7	26.75
43		269.492		.511	37.8	26.67	43		262.447		.085	54.9	26.75
44		269.371		.504	38.1	26.67	44		262.332		.078	55.2	26.75
45		269.251		.497	38.4	26.67	45		262.217		.071	55.5	26.76
46		269.131		.490	38.7	26.67	46		262.103		.064	55.8	26.76
47		269.012		.483	39.0	26.67	47		261.988		.057	56.1	26.76
48		268.892		.476	39.2	26.67	48		261.874		.049	56.4	26.76
49		268.772		.469	39.5	26.67	49		261.760		.042	56.7	26.76
50	18.0	268.653	.020	191.462	10° 39.8'	26.68	50	18.5	261.646	.019	191.035	10° 56.9'	26.76
51		268.533		.455	40.1	26.68	51		261.532		.028	57.2	26.77
52		268.414		.448	40.4	26.68	52		261.418		.021	57.5	26.77
53		268.295		.441	40.7	26.68	53		261.304		.013	57.8	26.77
54		268.175		.434	41.0	26.68	54		261.190		.006	58.1	26.77
55		268.056		.427	41.2	26.68	55		261.076		190.999	58.4	26.77
56		267.937		.420	41.5	26.68	56		260.963		.992	58.7	26.77
57		267.818		.413	41.8	26.69	57		260.849		.985	59.0	26.77
58		267.700		.406	42.1	26.69	58		260.736		.977	59.2	26.78
59		267.581		.399	42.4	26.69	59		260.622		.970	59.5	26.78
60	18.1	267.462	.020	191.392	10° 42.7'	26.69	60	18.5	260.509	.019	190.963	10° 59.8'	26.78

for Arcs of 100 Ft, and Skew Distances for Widths of 25 Ft

	22°						[illegible]°					
	Chord for 50-foot Arc = 49.92						Chord for 50-foot Arc = 49.92					
M	Ext Feet	Radius Feet	Diff 10″	Arc Feet	Def Arc 100 Feet	Skew 25 Ft	Ext Feet	Radius Feet	Diff 10″	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	18.5	260.509	.019	190.963	10° 59.8′	26.78	9.0	253.865	.018	[illegible]	11° 17.1′	26.87
1		260.396		.956	11° 00.1′	26.78		253.757		.516	17.4	26.87
2		260.283		.948	00.4	26.78		253.648		.509	17.7	26.87
3		260.169		[illegible]	00.7	[illegible]		253.540		.501	17.9	26.87
4		260.057		[illegible]	01.0	26.78		253.432		.494	18.2	26.88
5		259.944		[illegible]	01.2	26.79		253.324		.486	18.8	26.88
6		259.831		[illegible]	01.5	26.79		253.217		.479	18.5	26.88
7		259.718		.912	01.8	26.79		253.109		.471	19.1	26.88
8		259.606		.905	02.1	26.79		253.001		.464	19.4	26.88
9		259.493		.898	[illegible]	26.79		252.894		.456	19.7	26.88
10	18.6	259.381	.019	190.890	11° 02.7′	26.79	9.1	252.786	.018	190.449	11° 20.0′	26.89
11		259.268		.883	03.0	26.80		"52.679		.441	20.3	26.89
12		259.156		.876	03.3	26.80		252.571		.434	20.6	26.89
13		259.044		.868	03.5	26.80		252.464		.427	20.8	26.89
14		258.932		.861	03.8	26.80		252.357		.419	21.1	26.89
15		258.820		.854	04.1	26.80		252.250		.412	21.4	26.89
16		258.708		.847	04.4	26.80		252.142		.404	21.7	[illegible]
17		258.596		.839	04.7	26.80		252.036		.397	22.0	26.90
18		258.484		.832	05.0	26.81		251.929		.389	22.3	26.90
19		258.373		.825	05.3	26.81		251.822		.382	22.6	26.90
20	18.7	258.261	.019	190.818	11° 05.6′	26.81	9.1	251.715	.018	190.374	11° 22.9′	26.90
21		258.149		.810	05.8	26.81		251.608		.367	23.2	26.90
22		258.038		.803	06.1	26.81		251.502		.359	23.4	26.90
23		257.927		.796	06.4	26.81		251.395		.352	23.7	26.91
24		257.815		[illegible]	06.7	26.81		251.289		.344	24.0	26.91
25		257.704		.781	07.0	26.82		251.183		.337	24.3	26.91
26		257.593		.774	07.3	26.82		251.076		.329	24.6	26.91
27		257.482		.766	07.6	26.82		250.970		.322	24.9	26.91
28		257.371		.759	07.9	26.82		250.864		.314	25.2	26.91
29		257.260		.752	08.1	26.82		250.758		.307	25.5	26.91
30	18.8	257.150	.018	190.744	11° 08.4′	26.82	9.2	250.652	.018	190.299	11° 25.8′	26.92
31		257.039		.737	08.7	26.83		250.546		.292	26.1	26.92
32		256.928		.730	09.0	26.83		250.440		.284	26.3	26.92
33		256.818		.722	09.3	26.83		250.335		.277	26.6	26.92
34		256.707		.715	09.6	26.83		250.229		.269	[illegible]	26.92
35		256.597		.708	09.9	26.83		250.123		.262	27.2	26.92
36		256.487		.700	10.2	26.83		250.018		.254	27.5	26.93
37		256.377		.693	10.5	26.83		249.012		.247	27.8	26.93
38		256.266		.686	10.7	26.84		249.807		.239	28.1	26.93
39		256.156		.678	11.0	26.84		249.702		.232	28.4	26.93
40	18.8	256.046	.018	100.671	11° 11.3′	26.84	9.3	249.597	[illegible]	190.224	11° 28.7′	26.93
41		255.937		.664	11.6	26.84		249.492		.217	28.9	26.93
42		255.827		.656	11.9	26.84		249.386		.209	29.2	26.93
43		255.717		.649	12.2	26.84		249.282		.202	29.5	26.94
44		255.608		.642	12.5	26.85		249.177		.194	29.8	26.94
45		255.498		.634	12.8	26.85		249.072		.186	30.1	26.94
46		255.389		.627	13.0	26.85		248.967		.179	30.4	26.94
47		255.279		.619	13.3	26.85		248.862		.171	30.7	26.94
48		255.170		.612	13.6	26.85		248.758		.164	31.0	26.94
49		255.061		[illegible]	13.9	26.85		248.653		.156	31.3	26.95
50	18.9	254.952	.018	190.597	11° 14.2′	26.85	9.4	248.549	.017	190.149	11° 31.6′	26.95
51		254.843		.590	14.5	26.86		248.445		.141	31.9	26.95
52		254.734		.582	14.8	[illegible]		248.340		.134	32.1	26.95
53		[illegible]		.575	15.1	26.86		248.236		.126	32.4	26.95
54		254.516		.568	15.4	26.86		248.132		.118	32.7	26.95
55		254.407		.560	15.6	26.86		248.028		.111	33.0	26.96
56		254.299		.553	15.9	26.86		247.924		.103	33.3	[illegible]
57		254.190		.546	16.2	26.87		247.820		.096	33.6	26.96
58		254.082		.538	16.5	26.87		247.716		.088	33.9	26.96
59		253.973		.531	16.8	26.87		247.612		.081	34.2	26.96
60	19.0	253.865	.018	[illegible]	11° 17.1′	26.87	9.4	247.509	.017	190.073	11° 34.5′	26.96

Table VII.—Externals, Radii, Arcs for Tangents of 100 Ft, Deflections

Chord for 50-foot Arc = 49.91

			Diff 10″	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	19.4	247.509	[redacted]	190.073	11° 34.5′	26.96
1		247.405		.065	34.8	26.96
2		247.302		.058	35.1	26.97
3		247.198		.050	35.3	26.97
4		247.096		.043	35.6	26.97
5		246.991		.035	[redacted]	26.97
6		246.888		.027	36.2	26.97
7		246.785		.020	36.5	26.97
8		246.682		[redacted]	36.8	26.98
9		246.579		.004	37 1	[redacted]
10	19.5	246.476	[redacted]	189.997	11° 37.4′	26.98
11		246.373		.989	37.7	26.98
12		246.270		.982	38.0	26.98
13		246.168		.974	38.3	26.98
14		246.065		.966	38.5	26.99
15		245.962		.959	38.8	26.99
16		245.860		.951	39.1	26.99
17		245.757		.943	39.4	26.99
18		245.655		.936	39.7	26.99
19		245.553		.928	[redacted]	
20	19.6	245.451	.017	189.920	11° 40.3′	27.00
21		245.349		.913	40.6	27.00
22		245.246		.905	40.9	27.00
23		245.144		.897	41.2	27.00
24		245.043		.890	41.5	27.00
25		244.941		.882	41.8	27.00
26		244.839		.874	42.0	27.00
27		244.737		.867	42.3	27.01
28		244.636		.859	42.6	27.01
29		244.534		.851	42.9	27.01
30	19.7	244.433	.017	[redacted]	11° 43.2′	27.01
31		244.331		.836	43.5	27.01
32		244.230		.828	[redacted]	27.01
33		244.129		.821	44.1	27.02
34		[redacted]		[redacted]	44.4	27.02
35		243.926		.805	44.7	27.02
36		243.825		.798	45.0	27.02
37		243.724		.790	45.3	27.02
38		243.623		.782	45.5	27.02
39		243.523		774	45.8	27.03
40	19.7	243.422	.017	189.767	11° 46.1′	27.03
41		243.321		.759	46.4	27 03
42		243.220		.751	46.7	[redacted]
43		243.120		744	47.0	27.03
44		243.019		.736	47.3	27.03
45		242.919		.728	47.6	27.04
46		242.819		.720	47.9	27.04
47		242.718		.713	48.2	27.04
48		242.618		.705	48.5	27.04
49		242.518		.697	48.8	27.04
50	19.8	242.418	.017	189.689	11° 49.1′	27.04
51		242.318		.682	49.3	27.05
52		242.218		.674	49.6	27.05
53		242.118		.666	49.9	27.05
54		242.019		.658	50.2	27.05
55		241.919		.651	50.5	27.05
56		241.819		.643	50.8	27.05
57		241.720		.635	51.1	27.05
58		241.620		.627	51.4	27.06
59		241.521		.620	51.7	27.06
60	19.9	241.421	.017	189.612	11° 52.0′	27.06

Chord for 50-foot Arc = 49.91

M	E Ft				Def Arc 100 Feet	Skew 25 Ft
0	19.9	241.421	[redacted]	189.612	11° 52.0′	27.06
1		241.322		.604	52.3	27.06
2		241.223		.596	52.6	27.06
3		241 124		.588	52.9	27.06
4		241.025		.581	53.2	27.07
5		240.926		.573	53.4	27.07
6		240.827		.565	53.7	27.07
7		240.728		.557	54.0	27.07
8		240.629		.549	54.3	27.07
9		240.530		.542	54.6	27.07
10	20.0	240.432	[redacted]	189.534	11° 54.9′	27.08
11		240.333		.526	55.2	27.08
12		240.235		.518	55.5	27.08
13		240.136		.510	55.8	27.08
14		240.038		.503	56.1	27.08
15		239.939		.495	56.4	27.08
16		239.841		.487	56.7	27.09
17		239.743		.479	57.0	27.09
18		239.645		.471	57.3	27.09
19		239.547		.464	57.6	27.09
20	20.0	239.449	.016	189.456	11° 57.8′	27.09
21		239.351		.448	58.1	27.09
22		239.253		.440	58.4	27.10
23		239.155		.432	58.7	27.10
24		239.058		.424	59.0	27.10
25		238.960		.416	59.3	27 10
26		238.863		.409	59.6	27.10
27		238.765		[redacted]	59.9	27 10
28		238.668		.393	12° 00.2′	27.11
29		238.570		.385	00.5	27.11
30	20.1	238.473	.016	189.377	12° 00.8′	27.11
31		238.376		.369	01 1	27.11
32		238.279		.361	01.4	27.11
33		238.181		.354	01.7	27.11
34		238.084		.346	02.0	27.12
35		237.988		.338	02.3	27.12
36		237.891		.330	02.5	27.12
37		237.794		.322	02.8	27.12
38		237.697		.314	03.1	27.12
39		237.600		.306	03.4	27.12
40	20.2	237.504	[redacted]	189.298	12° 03.7′	27.13
41		237.407		.291	04.0	27.13
42		237.311		.283	04.3	27.13
43		237.214		.275	04.6	27.13
44		237.118		[redacted]	04.9	27.13
45		237.022		.259	05.2	27.13
46		236.925		.251	05.5	27 14
47		236.829		.243	05.8	27.14
48		236.733		.235	06.1	27.14
49		236.637		.227	06.4	27.14
50	20.3	236.541	.016	189.219	12° 06.7′	27.14
51		236.445		.211	07.0	27.14
52		236.349		.203	07.3	27 15
53		236.254		.195	07.6	27.15
54		[redacted]		.188	07.8	27 15
55		236.062		.180	08.1	27.15
56		235.967		.172	08.4	27.15
57		235.871		.164	08.7	27.15
58		235.776		.156	09.0	27.16
59		235.681		.148	[redacted]	27.16
60	[redacted]	235.585	.016	189.140	12° 09.6′	27.16

for Arcs of 100 Ft, and Skew Distances for Widths of 25 Ft

46° — Chord for 50-foot Arc = 49.91

M	Ext Feet	Radius Feet	Diff 10″	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	20.3	235.585	.016	189.140	12° 09.6′	27.16
1		235.490		.132	09.9	27.16
2		235.395		.124	10.2	27.16
3		235.300		.116	10.5	27.16
4		235.205		.108	10.8	27.17
5		235.110		.100	11.1	27.17
6		235.015		.092	11.4	27.17
7		234.920		.084	11.7	27.17
8		234.825		.076	12.0	27.17
9		234.730		.068	12.3	27.17
10	20.4	234.636	.016	189.060	12° 12.6′	27.18
11		234.541		.052	12.9	27.18
12		234.447		.044	13.2	27.18
13		234.352		.036	13.5	27.18
14		234.258		.028	13.8	27.18
15		234.164		.020	14.0	27.18
16		234.069		.012	14.3	27.19
17		233.975		.004	14.6	27.19
18		233.881		188.996	14.9	27.19
19		233.787		.988	15.2	27.19
20	20.5	233.693	.016	188.980	12° 15.5′	27.19
21		233.599		.972	15.8	27.19
22		233.505		.964	16.1	27.20
23		233.411		.956	16.4	27.20
24		233.317		.948	16.7	27.20
25		233.224		.940	17.0	27.20
26		233.130		.932	17.3	27.20
27		233.037		.924	17.6	27.20
28		232.943		.916	17.9	27.21
29		232.850		.908	18.2	27.21
30	20.6	232.756	.016	188.900	12° 18.5′	27.21
31		232.663		.892	18.8	27.21
32		232.570		.884	19.1	27.21
33		232.477		.876	19.4	27.21
34		232.383		.868	19.7	27.22
35		232.290		.860	20.0	27.22
36		232.197		.852	20.3	27.22
37		232.105		.843	20.6	27.22
38		232.012		.835	20.9	27.22
39		231.919		.827	21.2	27.23
40	20.6	231.826	.015	188.819	12° 21.4′	27.23
41		231.733		.811	21.7	27.23
42		231.641		.803	22.0	27.23
43		231.548		.795	22.3	27.23
44		231.456		.787	22.6	27.23
45		231.363		.779	22.9	27.24
46		231.271		.771	23.2	27.24
47		231.179		.763	23.5	27.24
48		231.086		.754	23.8	27.24
49		230.994		.746	24.1	27.24
50	20.7	230.902	.015	188.738	12° 24.4′	27.24
51		230.810		.730	24.7	27.25
52		230.718		.722	25.0	27.25
53		230.626		.714	25.3	27.25
54		230.534		.706	25.6	27.25
55		230.442		.698	25.9	27.25
56		230.351		.690	26.2	27.25
57		230.259		.682	26.5	27.26
58		230.167		.673	26.8	27.26
59		230.076		.665	27.1	27.26
60	20.8	229.984	.015	188.657	12° 27.4′	27.26

47° — Chord for 50-foot Arc = 49.90

M	Ext Feet	Radius Feet	Diff 10″	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	20.8	229.984	.015	188.657	12° 27.4′	27.26
1		229.893		.649	27.7	27.26
2		229.801		.641	28.0	27.26
3		229.710		.633	28.3	27.27
4		229.619		.625	28.6	27.27
5		229.528		.616	28.9	27.27
6		229.437		.608	29.2	27.27
7		229.345		.600	29.5	27.27
8		229.254		.592	29.8	27.27
9		229.163		.584	30.1	27.28
10	20.9	229.073	.015	188.576	12° 30.4′	27.28
11		228.982		.567	30.7	27.28
12		228.891		.559	31.0	27.28
13		228.800		.551	31.3	27.28
14		228.710		.543	31.6	27.29
15		228.619		.535	31.9	27.29
16		228.528		.526	32.1	27.29
17		228.438		.518	32.4	27.29
18		228.348		.510	32.7	27.29
19		228.257		.502	33.0	27.29
20	21.0	228.167	.015	188.494	12° 33.3′	27.30
21		228.077		.486	33.6	27.30
22		227.987		.477	33.9	27.30
23		227.896		.469	34.2	27.30
24		227.806		.461	34.5	27.30
25		227.716		.453	34.8	27.30
26		227.626		.444	35.1	27.31
27		227.537		.436	35.4	27.31
28		227.447		.428	35.7	27.31
29		227.357		.420	36.0	27.31
30	21.0	227.267	.015	188.412	12° 36.3′	27.31
31		227.178		.403	36.6	27.31
32		227.088		.395	36.9	27.32
33		226.999		.387	37.2	27.32
34		226.909		.379	37.5	27.32
35		226.820		.370	37.8	27.32
36		226.730		.362	38.1	27.32
37		226.641		.354	38.4	27.33
38		226.552		.346	38.7	27.33
39		226.463		.338	39.0	27.33
40	21.1	226.374	.015	188.329	12° 39.3′	27.33
41		226.285		.321	39.6	27.33
42		226.196		.313	39.9	27.33
43		226.107		.304	40.2	27.34
44		226.018		.296	40.5	27.34
45		225.929		.288	40.8	27.34
46		225.840		.280	41.1	27.34
47		225.751		.271	41.4	27.34
48		225.663		.263	41.7	27.34
49		225.574		.255	42.0	27.35
50	21.2	225.486	.015	188.246	12° 42.3′	27.35
51		225.397		.238	42.6	27.35
52		225.309		.230	42.9	27.35
53		225.221		.222	43.2	27.35
54		225.132		.213	43.5	27.36
55		225.044		.205	43.8	27.36
56		224.956		.197	44.1	27.36
57		224.868		.188	44.4	27.36
58		224.780		.180	44.7	27.36
59		224.692		.172	45.0	27.36
60	21.3	224.604	.015	188.164	12° 45.3′	27.37

Table VII.—Externals, Radii, Arcs for Tangents of 100 Ft, Deflections

48°						
Chord for 50-foot Arc = 49.90						
M	Ext Feet	Radius Feet	Diff 10″	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	21.3	224.604	.015	188.164	12° 45.3′	27.37
1		224.516		.155	45.6	27.37
2		224.428		.147	45.9	27.37
3		224.340		.138	46.2	27.37
4		224.252		.130	46.5	27.37
5		224.165		.122	46.8	27.37
6		224.077		.113	47.1	27.38
7		223.990		.105	47.4	27.38
8		223.902		.097	47.7	27.38
9		223.815		.088	48.0	27.38
10	21.3	223.727	.015	188.080	12° 48.3′	27.38
11		223.640		.072	48.6	27.39
12		223.553		.063	48.9	27.39
13		223.466		.055	49.2	27.39
14		223.378		.047	49.5	27.39
15		223.291		.038	49.8	27.39
16		223.204		.030	50.1	27.39
17		223.117		.022	50.4	27.40
18		223.030		.013	50.7	27.40
19		222.944		.005	51.0	27.40
20	21.4	222.857	.014	187.997	12° 51.3′	27.40
21		222.770		.988	51.6	27.40
22		222.683		.980	51.9	27.41
23		222.597		.971	52.2	27.41
24		222.510		.963	52.5	27.41
25		222.424		.955	52.8	27.41
26		222.337		.946	53.1	27.41
27		222.251		.938	53.4	27.41
28		222.164		.929	53.7	27.42
29		222.078		.921	54.0	27.42
30	21.5	221.992	.014	187.912	12° 54.3′	27.42
31		221.906		.904	54.6	27.42
32		221.819		.896	54.9	27.42
33		221.733		.887	55.2	27.42
34		221.647		.879	55.5	27.43
35		221.561		.870	55.8	27.43
36		221.475		.862	56.1	27.43
37		221.390		.854	56.4	27.43
38		221.304		.845	56.7	27.43
39		221.218		.837	57.0	27.44
40	21.6	221.132	.014	187.828	12° 57.3′	27.44
41		221.047		.820	57.6	27.44
42		220.961		.811	57.9	27.44
43		220.876		.803	58.2	27.44
44		220.790		.795	58.5	27.44
45		220.705		.786	58.8	27.45
46		220.619		.778	59.1	27.45
47		220.534		.769	59.4	27.45
48		220.449		.761	59.7	27.45
49		220.364		.752	13° 00.0′	27.45
50	21.6	220.278	.014	187.744	13° 00.3′	27.46
51		220.193		.735	00.6	27.46
52		220.108		.727	00.9	27.46
53		220.023		.718	01.2	27.46
54		219.938		.710	01.5	27.46
55		219.854		.701	01.8	27.46
56		219.769		.693	02.1	27.47
57		219.684		.684	02.4	27.47
58		219.599		.676	02.7	27.47
59		219.515		.667	03.0	27.47
60	21.7	219.430	.014	187.659	13° 03.3′	27.47

49°						
Chord for 50-foot Arc = 49.89						
M	Ext Feet	Radius Feet	Diff 10″	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	21.7	219.430	.014	187.659	13° 03.3′	27.47
1		219.345		.650	03.6	27.48
2		219.261		.642	03.9	27.48
3		219.177		.633	04.2	27.48
4		219.092		.625	04.5	27.48
5		219.008		.616	04.8	27.48
6		218.923		.608	05.1	27.48
7		218.839		.599	05.5	27.49
8		218.755		.591	05.8	27.49
9		218.671		.582	06.1	27.49
10	21.8	218.587	.014	187.574	13° 06.4′	27.49
11		218.503		.565	06.7	27.49
12		218.419		.557	07.0	27.50
13		218.335		.548	07.3	27.50
14		218.251		.540	07.6	27.50
15		218.167		.531	07.9	27.50
16		218.084		.523	08.2	27.50
17		218.000		.514	08.5	27.50
18		217.916		.505	08.8	27.51
19		217.833		.497	09.1	27.51
20	21.9	217.749	.014	187.488	13° 09.4′	27.51
21		217.666		.480	09.7	27.51
22		217.582		.471	10.0	27.51
23		217.499		.463	10.3	27.52
24		217.416		.454	10.6	27.52
25		217.332		.445	10.9	27.52
26		217.249		.437	11.2	27.52
27		217.166		.428	11.5	27.52
28		217.083		.420	11.8	27.53
29		217.000		.411	12.1	27.53
30	21.9	216.917	.014	187.402	13° 12.4′	27.53
31		216.834		.394	12.7	27.53
32		216.751		.385	13.0	27.53
33		216.668		.377	13.3	27.53
34		216.585		.368	13.6	27.54
35		216.503		.360	13.9	27.54
36		216.420		.351	14.2	27.54
37		216.337		.342	14.5	27.54
38		216.255		.334	14.8	27.54
39		216.172		.325	15.1	27.55
40	22.0	216.090	.014	187.317	13° 15.4′	27.55
41		216.007		.308	15.7	27.55
42		215.925		.299	16.1	27.55
43		215.842		.291	16.4	27.55
44		215.760		.282	16.7	27.55
45		215.678		.273	17.0	27.56
46		215.596		.265	17.3	27.56
47		215.514		.256	17.6	27.56
48		215.432		.247	17.9	27.56
49		215.350		.239	18.2	27.56
50	22.1	215.268	.014	187.230	13° 18.5′	27.57
51		215.186		.221	18.8	27.57
52		215.104		.213	19.1	27.57
53		215.022		.204	19.4	27.57
54		214.940		.196	19.7	27.57
55		214.859		.187	20.0	27.58
56		214.777		.178	20.3	27.58
57		214.695		.170	20.6	27.58
58		214.614		.161	20.9	27.58
59		214.532		.152	21.2	27.58
60	22.2	214.451	.014	187.144	13° 21.5′	27.58

for Arcs of 100 Ft, and Skew Distances for Widths of 25 Ft

50°							51°						
Chord for 50-foot Arc = 49.89							Chord for 50-foot Arc = 49.88						
M	Ext Feet	Radius Feet	Diff 10″	Arc Feet	Def Arc 100 Feet	Skew 25 Ft	M	Ext Feet	Radius Feet	Diff 10″	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	22.2	214.451	[illegible]	187.144	13° 21.5′	27.58	0	.6	209.654	.013	186.617	13° 39.9′	27.70
1		214.369		.135	21.8	27.59	1		209.576		.608	40.2	27.70
2		214.288		.126	22.1	27.59	2		209.498		.599	40.5	27.70
3		214.207		.117	22.4	27.59	3		209.419		.590	40.8	27.70
4		214.125		.109	22.7	27.59	4		209.341		.582	41.1	27.71
5		214.044		.100	23.0	27.59	5		209.263		.573	41.4	27.71
6		213.963		.091	23.4	27.60	6		209.184		.564	41.7	27.71
7		213.882		.083	23.7	27.60	7		209.106		.555	42.0	27.71
8		213.801		.074	24.0	27.60	8		209.028		.546	42.3	27.71
9		213.720		.065	24.3	27.60	9		208.950		.537	42.6	27.72
10	22.2	213.639	.014	187.056	13° 24.6′	27.60	10	7	208.872	.013	186.528	13° 42.9′	27.72
11		213.558		.048	24.9	27.61	11		208.794		.519	43.2	27.72
12		213.477		.039	25.2	27.61	12		208.716		.510	[illegible]	27.72
13		213.396		.030	25.5	27.61	13		208.638		.501	[illegible]	27.72
14		213.316		.022	25.8	27.61	14		208.560		.493	44.2	27.73
15		213.235		[illegible]	26.1	27.61	15		208.483		.484	44.5	27.73
16		213.154		.004	26.4	27.61	16		208.405		.475	44.8	27.73
17		213.074		186.996	26.7	27.62	17		208.327		.466	45.1	27.73
18		212.993		.987	27.0	27.62	18		208.250		.457	45.4	27.73
19		212.913		.978	27.3	27.62	19		208.172		.448	45.7	27.73
20	22.3	212.832	[illegible]	186.969	13° 27.6′	27.62	20	.8	[illegible]	.013	186.439	13° 46.0′	27.74
21		212.752		.961	27.9	27.62	21		208.017		.430	46.3	27.74
22		212.671		.952	28.2	27.63	22		207.939		.421	46.6	27.74
23		212.591		.943	28.5	27.63	23		207.862		.412	46.9	27.74
24		212.511		.934	28.8	27.63	24		207.785		[illegible]	47.2	27.74
25		212.431		.925	29.1	27.63	25		207.707		.394	[illegible]	27.75
26		212.350		.917	29.5	27.63	26		207.630		.385	47.9	27.75
27		212.270		.908	29.8	27.64	27		207.553		.376	48.2	27.75
28		212.190		.899	30.1	27.64	28		207.476		.368	48.5	27.75
29		212.110		.890	30.4	27.64	29		207.399		[illegible]	48.8	27.75
30	22.4	212.030	[illegible]	186.882	13° 30.7′	27.64	30	.9	207.321	.013	186.350	13° 49.1′	27.76
31		211.950		.873	31.0	27.64	31		207.244		.341	49.4	27.76
32		211.871		.864	31.3	27.64	32		207.167		[illegible]	49.7	27.76
33		211.791		.855	31.6	27.65	33		207.090		.323	50.0	27.76
34		211.711		.846	31.9	27.65	34		207.014		.314	50.3	27.76
35		211.631		.838	32.2	27.65	35		206.937		.305	50.6	27.77
36		211.552		.829	32.5	27.65	[illegible]		206.860		.296	50.9	27.77
37		211.472		.820	32.8	27.65	37		206.783		.287	51.2	27.77
38		211.392		.811	33.1	27.66	38		206.706		.278	51.6	27.77
39		211.313		.803	33.4	27.66	39		206.630		.269	51.9	27.77
40	22.5	211.233	.013	186.794	13° 33.7′	27.66	40	9	206.553	.013	186.260	13° 52.2′	27.78
41		211.154		.785	34.0	27.66	41		206.477		.251	52.5	[illegible]
42		211.075		.776	34.3	27.66	42		206.400		.242	52.8	27.78
43		210.995		.767	34.7	27.67	43		206.324		.233	53.1	27.78
44		210.916		.758	35.0	27.67	44		206.247		.224	53.4	27.78
45		210.837		.750	35.3	27.67	45		206.171		.215	53.7	27.79
46		210.758		.741	35.6	27.67	46		206.094		.206	54.0	27.79
47		210.679		.732	35.9	27.67	47		206.018		.197	54.3	[illegible]
48		210.600		.723	36.2	27.68	48		205.942		.188	54.6	27.79
49		210.521		.714	36.5	27.68	49		205.866		.179	55.0	27.79
50	22.6	210.442	.013	186.705	13° 36.8′	27.68	50	.0	205.790	.013	186.170	13° 55.3′	27.80
51		210.363		.697	37.1	27.68	51		205.713		.161	55.6	27.80
52		210.284		.688	37.4	27.68	52		205.637		.152	55.9	27.80
53		210.205		.679	37.7	27.68	53		205.561		.143	56.2	27.80
54		210.126		.670	38.0	27.69	54		205.485		.134	56.5	27.80
55		210.047		[illegible]	38.3	27.69	55		205.409		.125	56.8	27.81
56		209.969		.652	38.6	27.69	56		205.333		.116	57.1	27.81
57		209.890		.644	38.9	27.69	57		205.258		.107	57.4	27.81
58		209.811		.635	39.2	27.69	58		205.182		.098	57.7	27.81
59		209.733		.626	39.6	27.70	59		205.106		.089	58.0	27.81
60	22.6	209.654	.013	186.617	13° 39.9′	27.70	60	.1	205.030	.013	186.080	13° 58.4′	27.82

Table VII.—Externals, Radii, Arcs for Tangents of 100 Ft, Deflections

52°

Chord for 50-foot Arc = 49.88

M	Ext Feet	Radius Feet	Diff 10″	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	23.1	205.030	.013	[illegible]	13° 58.4′	27.82
1		204.955		.071	58.7	27.82
2		204.879		.062	59.0	27.82
3		204.804		.052	59.3	27.82
4		204.728		.043	59.6	27.82
5		204.653		.034	59.9	27.82
6		204.577		.025	14° 00.2′	27.83
7		204.502		.016	00.5	27.83
8		204.426		.007	00.8	27.83
9		204.351		185.998	01.1	27.83
10	23.2	204.276	.013	185.989	14° 01.4′	27.83
11		204.201		.980	01.8	27.84
12		204.125		.971	02.1	27.84
13		204.050		.962	02.4	27.84
14		203.975		.953	02.7	27.84
15		203.900		.943	03.0	27.84
16		203.825		.934	03.3	27.85
17		203.750		.925	03.6	27.85
18		203.675		.916	03.9	27.85
19		203.600		.907	04.2	27.85
20	23.2	203.526	.012	185.898	14° 04.5′	27.85
21		203.451		.889	04.9	27.86
22		203.376		.880	05.2	27.86
23		203.301		.871	05.5	27.86
24		203.227		.861	05.8	27.86
25		203.152		.852	06.1	27.86
26		203.078		.843	06.4	27.87
27		203.003		.834	06.7	27.87
28		202.929		.825	07.0	27.87
29		202.854		.816	07.3	27.87
30	23.3	202.780	.012	185.807	14° 07.7′	27.87
31		202.706		.798	08.0	27.88
32		202.631		.789	08.3	27.88
33		202.557		.779	08.6	27.88
34		202.483		.770	08.9	27.88
35		202.409		.761	09.2	27.88
36		202.335		.752	09.5	27.89
37		202.261		.743	09.8	27.89
38		202.187		.734	10.1	27.89
39		202.113		.724	10.5	27.89
40	23.4	202.039	.012	185.715	14° 10.8′	27.89
41		201.965		.706	11.1	27.90
42		201.891		.697	11.4	27.90
43		201.817		.688	11.7	27.90
44		201.743		.678	12.0	27.90
45		201.670		.669	12.3	27.90
46		201.596		.660	12.6	27.91
47		201.522		.651	12.9	27.91
48		201.449		.642	13.3	27.91
49		201.375		.632	13.6	27.91
50	23.5	201.302	.012	185.623	14° 13.9′	27.91
51		201.228		.614	14.2	27.92
52		201.155		.605	14.5	27.92
53		201.081		.596	14.8	27.92
54		201.008		.586	15.1	27.92
55		200.935		.577	15.4	27.92
56		200.862		.568	15.8	27.93
57		200.788		.559	16.1	27.93
58		200.715		.550	16.4	27.93
59		200.642		.540	16.7	27.93
60	23.5	200.569	.012	185.531	14° 17.0′	27.94

53°

Chord for 50-foot Arc = 49.87

M	Ext Feet	Radius Feet	Diff 10″	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
	5	[illegible]	[illegible]	185.531	14° 17.0′	27.94
		200.496		.522	17.3	27.94
		200.423		.513	17.6	27.94
		200.350		.503	17.9	27.94
		200.277		.494	18.2	27.94
		200.204		.485	18.6	27.95
		200.131		.476	18.9	27.95
		200.059		.466	19.2	27.95
		199.986		.457	19.5	27.95
		199.913		.448	19.8	27.95
	6	199.841	.012	185.439	14° 20.1′	27.96
		199.768		.429	20.4	27.96
		199.695		[illegible]	20.7	27.96
		199.623		.411	21.1	27.96
		199.550		[illegible]	21.4	27.96
		199.478		.392	21.7	27.97
		199.406		.383	22.0	27.97
		199.333		.374	22.3	27.97
		199.261		.364	22.6	27.97
		199.189		.355	22.9	27.97
	7	199.116	.012	185.346	14° 23.3′	27.98
		199.044		.337	23.6	27.98
		198.972		.327	23.9	27.98
		198.900		.318	24.2	27.98
		198.828		.309	24.5	27.98
		198.756		.299	24.8	27.99
		198.684		.290	25.1	27.99
		198.612		.281	25.4	27.99
		198.540		.271	25.8	27.99
		198.468		.262	26.1	27.99
	8	198.396	.012	185.253	14° 26.4′	28.00
		198.325		.243	26.7	28.00
		198.253		.234	27.0	28.00
		198.181		.225	27.3	28.00
		198.110		.215	27.6	28.00
		198.039		.206	28.0	28.01
		197.966		.197	28.3	28.01
		197.895		.187	28.6	28.01
		197.823		.178	28.9	28.01
		197.753		.169	29.2	28.01
	9	197.681	.012	185.159	14° 29.5′	28.02
		197.609		.150	29.8	28.02
		197.538		.141	30.1	28.02
		197.467		.131	30.5	28.02
		197.395		[illegible]	30.8	28.03
		197.324		.112	31.1	28.03
		197.253		.103	31.4	28.03
		197.182		.094	31.7	28.03
		197.111		[illegible]	32.0	28.03
		197.040		.075	32.3	28.04
	9	196.969	.012	185.066	14° 32.7′	28.04
		196.898		.056	33.0	28.04
		196.827		.047	33.3	28.04
		196.756		.037	33.6	28.04
		196.685		.028	33.9	28.05
		196.614		.019	34.2	28.05
		196.544		.009	34.6	28.05
		196.473		.000	34.9	28.05
		196.402		184.990	35.2	28.05
		196.332		.981	35.5	28.06
	...0	196.261	.012	184.972	14° 35.8′	28.06

for Arcs of 100 Ft, and Skew Distances for Widths of 25 Ft

54°

Chord for 50-foot Arc = 49.86

M	Ext Feet	Radius Feet	Diff 10"	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	24.0	196.261	.012	184.972	14° 35.8'	28.06
1		196.191		.962	36.1	28.06
2		196.120		.953	36.4	28.06
3		196.050		.943	36.8	28.06
4		195.979		.934	37.1	28.07
5		195.909		.924	37.4	28.07
6		195.838		.915	37.7	28.07
7		195.768		.906	38.0	28.07
8		195.698		.896	38.3	28.07
9		195.628		.887	38.6	28.08
10	24.1	195.557	.012	184.877	14° 39.0'	28.08
11		195.487		.868	39.3	28.08
12		195.417		.858	39.6	28.08
13		195.347		.849	39.9	28.09
14		195.277		.839	40.2	28.09
15		195.207		.830	40.5	28.09
16		195.137		.820	40.9	28.09
17		195.067		.811	41.2	28.09
18		194.997		.802	41.5	28.10
19		194.928		.792	41.8	28.10
20	24.2	194.858	.012	184.783	14° 42.1'	28.10
21		194.788		.773	42.4	28.10
22		194.718		.764	42.7	28.10
23		194.649		.754	43.1	28.11
24		194.579		.745	43.4	28.11
25		194.509		.735	43.7	28.11
26		194.440		.726	44.0	28.11
27		194.370		.716	44.3	28.11
28		194.301		.707	44.6	28.12
29		194.231		.697	45.0	28.12
30	24.2	194.162	.012	184.688	14° 45.3'	28.12
31		194.093		.678	45.6	28.12
32		194.023		.669	45.9	28.13
33		193.954		.659	46.2	28.13
34		193.885		.650	46.5	28.13
35		193.816		.640	46.9	28.13
36		193.746		.631	47.2	28.13
37		193.677		.621	47.5	28.14
38		193.608		.612	47.8	28.14
39		193.539		.602	48.1	28.14
40	24.3	193.470	.012	184.592	14° 48.4'	28.14
41		193.401		.583	48.8	28.14
42		193.332		.573	49.1	28.15
43		193.263		.564	49.4	28.15
44		193.195		.554	49.7	28.15
45		193.126		.545	50.0	28.15
46		193.057		.535	50.3	28.15
47		192.988		.525	50.7	28.16
48		192.920		.516	51.0	28.16
49		192.851		.506	51.3	28.16
50	24.4	192.782	.011	184.497	14° 51.6'	28.16
51		192.714		.487	51.9	28.17
52		192.645		.478	52.2	28.17
53		192.577		.468	52.6	28.17
54		192.508		.458	52.9	28.17
55		192.440		.449	53.2	28.17
56		192.371		.439	53.5	28.18
57		192.303		.430	53.8	28.18
58		192.235		.420	54.2	28.18
59		192.166		.411	54.5	28.18
60	24.5	192.098	.011	184.401	14° 54.8'	28.18

55°

Chord for 50-foot Arc = 49.86

M	Ext Feet	Radius Feet	Diff 10"	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	24.5	192.098	.011	184.401	14° 54.8'	28.18
1		192.030		.391	55.1	28.19
2		191.962		.382	55.4	28.19
3		191.894		.372	55.7	28.19
4		191.826		.362	56.1	28.19
5		191.758		.353	56.4	28.20
6		191.690		.343	56.7	28.20
7		191.622		.334	57.0	28.20
8		191.554		.324	57.3	28.20
9		191.486		.314	57.7	28.20
10	24.5	191.418	.011	184.305	14° 58.0'	28.21
11		191.350		.295	58.3	28.21
12		191.282		.285	58.6	28.21
13		191.215		.276	58.9	28.21
14		191.147		.266	59.2	28.21
15		191.079		.256	59.6	28.22
16		191.012		.247	59.9	28.22
17		190.944		.237	15° 00.2'	28.22
18		190.876		.228	00.5	28.22
19		190.809		.218	00.8	28.23
20	24.6	190.741	.011	184.208	15° 01.2'	28.23
21		190.674		.199	01.5	28.23
22		190.607		.189	01.8	28.23
23		190.539		.179	02.1	28.23
24		190.472		.170	02.4	28.24
25		190.405		.160	02.7	28.24
26		190.337		.150	03.1	28.24
27		190.270		.140	03.4	28.24
28		190.203		.131	03.7	28.24
29		190.136		.121	04.0	28.25
30	24.7	190.069	.011	184.111	15° 04.3'	28.25
31		190.002		.102	04.7	28.25
32		189.935		.092	05.0	28.25
33		189.868		.082	05.3	28.26
34		189.801		.073	05.6	28.26
35		189.734		.063	05.9	28.26
36		189.667		.053	06.3	28.26
37		189.600		.043	06.6	28.26
38		189.533		.034	06.9	28.27
39		189.466		.024	07.2	28.27
40	24.8	189.400	.011	184.014	15° 07.5'	28.27
41		189.333		.005	07.9	28.27
42		189.266		183.995	08.2	28.27
43		189.200		.985	08.5	28.28
44		189.133		.975	08.8	28.28
45		189.067		.966	09.1	28.28
46		189.000		.956	09.5	28.28
47		188.934		.946	09.8	28.29
48		188.867		.936	10.1	28.29
49		188.801		.927	10.4	28.29
50	24.9	188.734	.011	183.917	15° 10.7'	28.29
51		188.668		.907	11.1	28.29
52		188.602		.897	11.4	28.30
53		188.535		.888	11.7	28.30
54		188.469		.878	12.0	28.30
55		188.403		.868	12.3	28.30
56		188.337		.858	12.7	28.31
57		188.271		.848	13.0	28.31
58		188.205		.839	13.3	28.31
59		188.139		.829	13.6	28.31
60	24.9	188.073	.011	183.819	15° 13.9	28.31

Table VII.—Externals, Radii, Arcs for Tangents of 100 Ft, Deflections

Chord for 50-foot Arc = 49.85							Chord for 50-foot Arc = 49.85						
					Def Arc 100 Feet	Skew 25 Ft	M	E F		ff y''	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	24.9	188.073	.011	183.819	15° 13.9'	28.31	0	25.4	184.177	.011	183.226	15° 33.3'	28.45
1		188.007		.809	14.3	28.32	1		184.113		.216	33.6	28.4
2		187.941		.800	14.6	28.32	2		184.049		.206	33.9	28.45
3		187.875		.790	14.9	28.32	3		183.986		.196	34.2	28.45
4		187.809		.780	15.2	28.32	4		183.922		.186	34.6	28.46
5		187.743		.770	15.5	28.33	5		183.858		.176	34.9	28.46
6		187.677		.760	[illegible]	28.33	6		183.794		.166	35.2	28.46
7		187.612		.750	16.2	28.33	7		183.731		.156	35.5	[illegible]
8		187.546		.741	16.5	28.33	8		183.667		.146	35.9	28.47
9		187.480		.731	16.8	28.33	9		183.604		.136	36.2	28.47
10	25.0	187.415	.011	183.721	15° 17.2'	28.34	10	25.5	183.540	.011	183.126	15° 36.5'	[illegible]
11		187.349		.711	17.5	28.34	11		183.476		.116	[illegible]	28.47
12		187.283		.701	17.8	28.34	12		183.413		[illegible]	37.2	28.47
13		187.218		.692	18.1	28.34	13		183.350		.096	37.5	28.48
14		187.152		[illegible]	18.4	28.34	14		183.286		.086	37.8	28.48
15		187.087		.672	18.8	28.35	15		183.223		.076	38.1	28.48
16		187.021		.662	19.1	28.35	16		183.159		.066	38.5	28.48
17		186.956		[illegible]	19.4	28.35	17		[illegible]		.056	38.8	28.49
18		186.891		[illegible]	19.7	28.35	18		[illegible]		.046	39.1	28.49
19		186.826		.633	20.0	28.36	19		182.969		.036	[illegible]	28.49
20	25.1	186.760	.011	183.623	15° 20.4'	28.36	20	25.6	182.906	.011	183.026	15° 39.8'	28.49
21		186.695		.613	20.7	28.36	21		182.843		.016	40.1	28.49
22		186.630		.603	21.0	28.36	22		182.780		.006	[illegible]	28.50
23		186.564		.593	21.3	28.36	23		182.717		182.996	40.7	28.50
24		186.499		.583	21.7	28.37	24		182.654		.986	41.1	28.50
25		186.434		.573	[illegible]	28.37	25		182.591		.976	41.4	28.50
26		186.369		.564	22.3	28.37	26		182.528		.966	41.7	28.51
27		186.304		.554	22.6	28.37	27		182.465		.956	42.0	28.51
28		186.239		.544	22.9	28.38	28		182.402		.946	[illegible]	28.51
29		186.174		.534	23.3	28.38	29		182.339		.935	[illegible]	28.51
30	25.2	186.109	.011	183.524	15° 23.6'	28.38	30	25.6	182.276	.010	182.925	15° 43.0'	28.52
31		186.044		.514	23.9	28.38	31		182.213		.915	43.3	28.52
32		185.979		.504	24.2	28.38	32		[illegible]		.905	43.7	28.53
33		185.914		[illegible]	24.6	28.39	33		182.087		.895	44.0	28.53
34		185.850		.484	24.9	28.39	34		182.025		.885	44.3	28.53
35		185.785		.475	25.2	28.39	35		181.962		.875	44.6	28.53
36		185.720		[illegible]	25.5	28.39	36		181.899		.865	45.0	28.53
37		185.655		.455	25.8	28.40	37		181.837		.855	45.3	28.53
38		185.591		[illegible]	26.2	28.40	38		181.774		.845	45.6	28.53
39		185.526		.435	26.5	28.40	39		181.711		.835	45.9	28.54
40	25.2	185.462	.011	183.425	15° 26.8'	28.40	40	25.7	181.649	.010	182.825	15° 46.3'	28.54
41		185.397		.415	27.1	28.40	41		181.586		.815	46.6	28.54
42		185.333		.405	27.5	28.41	42		181.524		.804	[illegible]	28.54
43		185.268		.395	27.8	[illegible]	43		[illegible]		.794	47.2	28.54
44		185.204		.385	28.1	28.41	44		181.399		.784	47.6	28.55
45		185.139		.375	28.4	[illegible]	45		181.337		.774	47.9	28.55
46		185.075		.366	28.7	28.42	46		181.274		.764	48.2	28.55
47		185.010		.356	29.1	28.42	47		181.212		.754	48.5	28.55
48		184.946		[illegible]	29.4	28.42	48		181.150		.744	48.9	28.56
49		184.882		.336	29.7	28.42	49		181.087		.734	49.2	28.56
50	25.3	184.818	.011	183.326	15° 30.0'	28.42	50	25.8	181.025	.010	182.723	15° 49.5'	28.56
51		184.753		.316	30.4	28.43	51		180.963		.713	49.8	28.56
52		184.689		.306	30.7	28.43	52		180.901		.703	50.2	28.57
53		184.625		[illegible]	31.0	28.43	53		180.839		.693	50.5	28.57
54		184.561		.286	31.3	28.43	54		180.777		.683	50.8	28.57
55		184.497		.276	31.7	[illegible]	55		[illegible]		[illegible]	51.2	28.57
56		184.433		.266	[illegible]	28.44	56		180.653		[illegible]	51.5	28.57
57		184.369		.256	32.3	28.44	57		180.591		.652	51.8	28.58
58		184.305		.246	[illegible]	28.44	58		180.529		.642	52.1	28.58
59		184.241		.236	32.9	28.45	59		180.467		.632	52.5	28.58
60	25.4	184.177	.011	183.226	15° 33.2'	28.45	60	25.9	180.405	.010	182.622	15° 52.8'	28.58

for Arcs of 100 Ft, and Skew Distances for Widths of 25 Ft

Chord for 50-foot Arc = [illegible]						
M	Ext Feet	Radius Feet	Diff 10″	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	25.9	180.406	[illegible]	182.632	15° 52.8′	28.58
1		180.343		.612	53.1	28.59
2		180.281		.602	53.4	28.59
3		180.219		[illegible]	53.8	28.59
4		180.158		.581	54.1	28.59
5		180.096		.571	[illegible]	28.60
6		180.034		.561	54.7	28.60
7		179.972		.551	55.1	28.60
8		179.911		.541	55.4	28.60
9		179.849		.530	55.7	28.60
10	25.9	179.788	.010	182.520	15° 56.1′	28.61
11		179.726		.510	56.4	28.61
12		179.665		.500	[illegible]	28.61
13		179.603		[illegible]	57.0	28.61
14		179.542		.479	57.4	28.62
15		[illegible]		.469	57.7	[illegible]
16		179.419		.459	58.0	28.62
17		179.357		.449	58.4	28.62
18		179.296		[illegible]	58.7	28.63
19		179.235		.428	59.0	28.63
20	26.0	179.174	.010	182.418	15° 59.3′	[illegible]
21		179.112		.408	59.7	28.63
22		179.051		.398	16° 00.0′	28.63
23		178.990		.387	00.3	28.64
24		178.929		.377	00.6	[illegible]
25		178.868		.367	01.0	28.64
26		178.807		.357	01.3	28.64
27		178.746		.346	01.6	28.65
28		178.685		.336	02.0	28.65
29		178.624		.326	02.3	28.65
30	26.1	178.563	.010	182.316	16° 02.6′	28.65
31		178.502		.305	02.9	28.66
32		178.441		.295	03.3	28.66
33		178.380		.285	03.6	28.66
34		178.319		.275	03.9	28.66
35		178.259		.264	04.3	28.67
36		178.198		.254	04.6	28.67
37		178.137		.244	04.9	28.67
38		178.077		.234	05.2	28.67
[illegible]		178.016		.223	05.6	28.67
40	26.2	177.955	.010	182.213	16° 05.9′	28.68
[illegible]		177.895		.203	06.2	28.68
42		177.834		.192	06.6	28.68
43		177.774		.182	06.9	28.68
44		177.713		.172	07.2	28.69
45		177.653		.161	07.5	28.69
46		177.592		[illegible]	07.9	28.69
47		177.532		.141	08.2	28.69
48		177.471		.131	08.5	28.70
49		177.411		.120	08.9	28.70
50	26.3	177.351	.010	182.110	16° 09.2′	28.70
51		177.290		.100	09.5	28.70
52		177.230		[illegible]	[illegible]	28.71
53		177.170		.079	10.2	28.71
[illegible]		177.110		.069	10.5	28.71
55		177.050		[illegible]	[illegible]	28.71
56		176.990		.048	11.2	28.71
57		176.929		.038	11.5	28.72
58		176.869		.027	11.8	28.72
59		176.809		[illegible]	12.2	28.72
60	26.3	176.749	.010	182.007	16° 12.5′	28.72

Chord for 50-foot Arc = 49.83						
M	Ext Feet	Radius Feet	Diff 10″	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	26.3	176.749	[illegible]	182.007	16° 12.5′	28.72
1		176.689		181.996	12.8	28.73
2		176.630		.986	13.2	28.73
3		176.570		[illegible]	13.5	28.73
4		176.510		.965	13.8	28.73
5		176.450		.955	14.1	28.74
6		176.390		.944	14.5	[illegible]
7		176.330		.934	14.8	28.74
8		176.271		[illegible]	15.1	28.74
9		176.211		[illegible]	15.5	28.75
10	26.4	176.151	[illegible]	181.903	16° 15.8′	28.75
11		176.091		.892	16.1	28.75
12		176.032		.882	16.5	28.75
13		175.972		[illegible]	16.8	28.75
14		175.913		.861	17.1	28.76
15		175.853		.851	17.4	28.76
16		175.794		.841	17.8	28.76
17		175.734		.830	18.1	28.76
18		175.675		.820	18.4	28.77
19		175.615		.809	18.8	28.77
20	26.5	175.556	.010	181.799	16° 19.1′	28.77
21		175.497		.789	19.4	28.77
22		175.437		.778	19.8	28.78
23		175.378		[illegible]	20.1	28.78
24		175.319		.757	20.4	28.78
25		175.259		.747	20.8	28.78
26		175.200		.736	21.1	28.79
27		175.141		.726	21.4	28.79
28		175.082		.715	21.8	28.79
29		175.023		.705	22.1	28.79
30	26.6	174.964	.010	181.695	16° 22.4′	28.80
31		174.905		[illegible]	22.7	28.80
32		174.846		.674	23.1	28.80
33		174.787		.663	23.4	28.80
34		174.728		.653	23.7	28.80
35		174.669		.642	24.1	28.81
36		174.610		.632	24.4	[illegible]
37		174.551		.621	24.7	28.81
38		174.492		.611	25.1	28.81
39		174.433		[illegible]	25.4	28.82
40	26.6	174.375	.010	181.590	16° 25.7′	28.82
41		174.316		.580	26.1	28.82
42		174.257		.569	26.4	28.82
43		174.198		.559	26.7	28.83
44		174.140		[illegible]	27.1	28.83
45		174.081		[illegible]	27.4	28.83
46		174.022		.527	27.7	28.83
47		173.964		.517	[illegible]	[illegible]
[illegible]		173.906		.506	[illegible]	[illegible]
49		173.847		.496	28.7	28.84
50	26.7	173.788	.010	181.485	16° 29.0′	[illegible]
51		[illegible]		.474	29.4	28.85
52		173.671		.464	29.7	28.85
[illegible]		173.613		.453	30.1	28.85
54		173.555		.443	[illegible]	28.85
55		173.496		.432	30.7	28.86
56		173.438		.422	31.1	28.86
57		173.380		.411	31.4	28.86
58		173.321		.401	31.7	28.86
59		173.263		.390	32.1	28.87
60	26.8	173.205	.010	[illegible]	16° 32.4′	28.87

Table VII.—Externals, Radii, Arcs for Tangents of 100 Ft, Deflections

60°

Chord for 50-foot Arc = 49.83

M	Ext Feet	Radius Feet	Diff 10"	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	26.8	173.206	.010	181.380	16° 32.4′	28.87
1		173.147		.369	32.7	28.87
2		173.089		.359	33.1	28.87
3		173.031		.348	[illegible]	28.87
4		172.973		.338	33.7	28.88
5		172.915		.327	34.1	28.88
6		172.857		.316	34.4	28.88
7		172.799		.306	34.7	28.88
8		172.741		.295	35.1	28.89
9		172.683		.285	35.4	28.89
10	26.9	172.625	.010	181.274	16° 35.7′	28.89
[illegible]		172.567		.264	36.1	28.89
12		172.509		.253	36.4	28.90
13		172.451		.242	36.7	28.90
14		172.393		.232	37.1	28.90
15		172.336		.221	37.4	28.90
16		172.278		.211	37.7	28.91
17		172.220		.200	38.1	28.91
18		172.163		.190	38.4	28.91
19		172.105		[illegible]	38.7	28.91
20	27.0	172.047	.010	181.169	16° 39.1′	28.92
21		171.990		.158	[illegible]	28.92
22		171.932		.147	39.7	28.92
23		171.875		.137	40.1	[illegible]
24		171.817		.126	40.4	28.93
25		171.760		115	40.7	28.93
26		171.702		.105	41.1	28.93
27		171.645		.094	41.4	28.93
28		171.588		.083	41.7	28.94
29		171.530		.073	42.1	28.94
30	27.0	171.473	.010	181.062	16° 42.4′	28.94
31		171.416		.052	42.8	28.94
32		171.358		.041	43.1	28.95
33		171.301		.030	43.4	28.95
34		171.244		.020	43.8	28.95
35		171.187		.009	44.1	28.95
36		171.129		180.998	44.4	28.96
37		171.072		.988	44.8	28.96
38		171.015		.977	45.1	[illegible]
39		170.958		.966	45.4	28.96
40	27.1	170.901	.010	180.956	16° 45.8′	28.97
41		170.844		945	46.1	28.97
42		170.787		.934	46.4	28.97
43		170.730		.924	46.8	28.97
44		170.673		.913	47.1	28.98
45		170.616		.902	47.5	28.98
46		170.560		.892	47.8	28.98
[illegible]		170.503		.881	48.1	28.98
48		170.446		.870	48.5	28.99
49		170.389		.860	48.8	28.99
50	27.2	170.332	.009	180.849	16° 49.1′	28.99
51		170.276		.838	49.5	28.99
52		170.219		.827	49.8	28.99
53		170.162		.817	50.1	29.00
54		170.106		.806	50.5	29.00
55		170.049		.795	50.8	29.00
56		169.992		.785	51.1	29.00
57		169.936		.774	51.5	29.01
58		169.879		.763	51.8	29.01
59		169.823		.753	52.2	29.01
60	27.2	169.766	.009	180.742	16° 52.5′	29.01

61°

for 50-foot Arc = 49.82

s	Diff 10"	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
06	.009	180.742	16° 52.5′	29.02
10		.731	52.8	29.02
53		.720	53.2	29.02
97		.710	53.5	29.03
41		.699	53.8	29.03
84		.688	54.2	29.03
28		.677	[illegible]	29.03
72		.666	54.9	29.03
16		.656	55.2	29.03
59		.645	55.5	29.04
03	.009	180.634	16° 55.9′	29.04
47		.623	56.2	29.04
91		.613	56.5	29.04
35		[illegible]	56.9	29.05
79		.591	57.2	29.05
22		.580	57.6	29.05
66		.570	57.9	29.05
10		[illegible]	58.2	29.06
54		.548	58.6	29.06
99		.537	58.9	29.06
43	.009	180.527	16° 59.2′	29.06
87		.516	59.6	29.07
31		.505	59.9	29.07
75		[illegible]	17° 00.3′	29.07
19		[illegible]	00.6	29.07
63		.472	00.9	29.08
08		[illegible]	01.3	29.08
52		.451	01.6	29.08
96		.440	01.9	29.08
41		[illegible]	02.3	29.09
85	[illegible]	180.418	17° 02.6′	29.09
29		[illegible]	03.0	29.09
74		.397	03.3	29.09
18		.386	03.6	29.10
63		.375	04.0	29.10
07		.364	04.3	29.10
52		.353	04.7	29.10
96		[illegible]	05.0	29.11
41		.332	05.3	29.11
86		.321	05.7	29.11
30	.009	180.310	17° 06.0′	29.12
75		.299	06.3	29.12
19		.288	06.7	29.12
64		.277	07.0	29.12
09		.267	07.4	29.12
53		.256	07.7	29.13
98		[illegible]	08.0	29.13
43		.234	08.4	29.13
88		.223	08.7	29.14
33		.212	09.1	29.14
78	.009	180.201	17° 09.4′	29.14
22		.190	09.7	29.14
67		.179	10.1	29.15
12		.169	10.4	29.15
57		[illegible]	10.8	29.15
02		.147	11.1	29.16
47		.136	11.4	29.16
92		.125	11.8	29.16
38		.114	12.1	29.16
83		.103	12.5	29.16
28	.009	180.092	17° 12.8′	29.17

for Arcs of 100 Ft, and Skew Distances for Widths of 25 Ft

[illegible]						
Chord for 50-foot Arc = 49.81						
M	Ext Feet	Radius Feet	Diff 10"	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	[illegible]	166.428	.009	180.092	17° 12.8′	[illegible]
1		166.373		.081	13.1	29.17
2		166.318		.070	13.5	29.17
3		166.264		[illegible]	13.8	29.17
4		166.209		.049	14.2	29.18
5		166.154		[illegible]	14.5	29.18
6		166.099		[illegible]	[illegible]	29.18
7		166.045		.016	15.2	29.18
8		165.990		[illegible]	15.5	29.19
9		165.935		179.994	15.9	29.19
10	27.8	165.881	.009	[illegible]	17° 16.2′	29.19
11		165.826		.972	16.6	29.19
12		165.772		.961	16.9	[illegible]
13		165.717		.950	17.2	29.20
14		165.663		.939	17.6	29.20
15		165.608		.928	17.9	29.20
16		165.554		.917	18.3	29.21
17		165.500		.906	18.6	29.21
18		165.445		.895	18.9	[illegible]
19		165.391		.884	19.3	29.21
20	27.9	165.337	.009	179.873	17° 19.6′	29.22
21		165.283		.862	20.0	29.22
22		165.228		.851	20.3	29.22
23		165.174		.840	20.6	29.22
24		165.120		.829	21.0	29.23
25		165.065		.818	21.3	29.23
26		165.011		.807	21.7	29.23
27		164.957		[illegible]	22.0	29.24
28		164.903		.785	22.4	29.24
29		164.849		.774	22.7	29.24
30	28.0	164.795	.009	179.763	17° 23.0′	29.24
31		164.741		.752	23.4	[illegible]
32		164.687		.741	23.7	[illegible]
33		164.633		.730	24.1	29.25
34		164.579		[illegible]	24.4	29.25
35		164.525		[illegible]	24.7	29.26
36		164.471		.697	25.1	29.26
37		164.417		.686	25.4	29.26
38		164.363		.675	25.8	29.26
39		164.309		.664	26.1	29.27
40	28.0	164.256	.009	179.653	17° 26.5′	29.27
41		164.202		.642	26.8	29.27
42		164.148		.631	27.1	29.27
43		164.095		.620	27.5	[illegible]
44		164.041		[illegible]	27.8	29.28
45		163.987		.598	28.2	29.28
46		163.934		.587	28.5	[illegible]
47		163.880		.576	28.9	29.29
48		163.826		.564	29.2	29.29
49		163.773		.553	29.5	29.29
50	[illegible]	163.719	.009	179.542	17° 29.9′	29.29
51		163.666		[illegible]	30.2	29.30
52		163.612		.520	30.6	29.30
53		163.559		.509	30.9	29.30
54		163.505		.498	31.3	29.31
55		163.452		.487	31.6	[illegible]
56		163.398		[illegible]	32.0	29.31
57		163.345		.465	32.3	29.31
58		163.292		.454	32.6	29.32
59		163.238		.442	33.0	29.32
60	28.2	163.185	.009	179.431	17° 33.3′	29.32

[illegible]						
M						
0	28.2	163.185	.009	179.431	17° 33.3′	29.32
1		163.132		.420	33.7	29.32
2		[illegible]		[illegible]	34.0	29.33
3		163.026		.398	[illegible]	29.33
4		162.972		.387	34.7	[illegible]
5		162.919		.376	35.0	29.33
6		162.866		.365	35.4	29.34
7		162.813		.353	35.7	29.34
8		162.760		.342	36.1	29.34
9		162.707		.331	36.4	29.34
10	28.3	162.654	.009	179.320	17° 36.8′	29.35
11		162.601		.309	37.1	29.35
12		162.548		.298	37.5	[illegible]
13		162.495		.287	37.8	29.35
14		162.442		.275	38.1	[illegible]
15		162.389		.264	38.5	29.36
16		162.336		.253	38.8	29.36
17		162.283		.242	39.2	29.37
18		162.230		.231	[illegible]	29.37
19		162.177		.220	[illegible]	29.37
20	28.4	162.125	.009	179.209	17° 40.2′	29.37
21		162.072		.197	[illegible]	29.38
22		162.019		.186	40.9	[illegible]
23		161.967		.175	41.3	29.38
24		161.914		[illegible]	41.6	29.38
25		161.861		.153	41.9	29.39
26		161.809		.141	42.3	29.39
27		161.756		.130	42.6	29.39
28		161.703		.119	43.0	29.39
29		161.651		.108	43.3	29.40
30	28.4	161.598	.009	179.097	17° 43.7′	29.40
31		161.546		.086	44.0	29.40
32		161.493		.074	[illegible]	[illegible]
33		161.441		.063	44.7	29.41
34		161.388		[illegible]	45.1	29.41
35		161.336		.041	[illegible]	29.41
36		161.283		.030	45.7	29.42
37		161.231		[illegible]	[illegible]	29.42
38		161.179		[illegible]	46.4	29.42
39		161.126		178.996	46.8	[illegible]
40	28.5	161.074	.009	178.985	17° 47.1′	29.43
41		161.022		.973	47.5	29.43
42		160.970		.962	47.8	29.43
43		160.917		.951	48.2	29.43
44		160.865		.939	[illegible]	29.44
45		160.813		.928	[illegible]	29.44
46		160.761		.917	49.2	29.44
47		160.709		.906	49.6	29.44
48		160.657		.894	[illegible]	29.45
49		160.605		.883	50.2	29.45
50	28.6	160.553	.009	178.872	17° 50.6′	29.45
51		160.501		.861	50.9	29.46
52		160.449		.849	51.3	29.46
53		160.397		.838	51.6	29.46
54		160.345		.827	52.0	29.46
55		160.293		.815	52.3	29.47
56		160.241		.804	52.7	29.47
57		160.189		.793	53.0	29.47
58		160.137		.782	53.4	29.47
59		160.085		.770	53.7	29.48
60	28.7	[illegible]	[illegible]	178.759	17° 54.1′	29.48

Table VII.—Externals, Radii, Arcs for Tangents of 100 Ft, Deflections

64° — Chord for 50-foot Arc = 49.80

M	Ext Feet	Radius Feet	Diff 10″	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	28.7	160.033	.009	178.759	17° 54.1′	29.48
1		159.982		.748	54.4	29.48
2		159.930		.736	54.8	29.48
3		159.878		.725	55.1	29.49
4		159.826		.714	55.5	29.49
5		159.775		.702	55.8	29.49
6		159.723		.691	56.2	29.50
7		159.672		.680	56.5	29.50
8		159.620		.668	56.9	29.50
9		159.568		.657	57.2	29.50
10	28.8	159.517	.009	178.646	17° 57.6′	29.51
11		159.465		.634	57.9	29.51
12		159.414		.623	58.2	29.51
13		159.362		.612	58.6	29.51
14		159.311		.600	58.9	29.52
15		159.259		.589	59.3	29.52
16		159.208		.578	59.6	29.52
17		159.156		.566	18° 00.0′	29.53
18		159.105		.555	00.3	29.53
19		159.054		.544	00.7	29.53
20	28.8	159.002	.009	178.532	18° 01.0′	29.53
21		158.951		.521	01.4	29.54
22		158.900		.510	01.7	29.54
23		158.849		.498	02.1	29.54
24		158.797		.487	02.4	29.54
25		158.746		.475	02.8	29.55
26		158.695		.464	03.1	29.55
27		158.644		.453	03.5	29.55
28		158.593		.441	03.8	29.55
29		158.542		.430	04.2	29.56
30	28.9	158.490	.009	178.418	18° 04.5′	29.56
31		158.439		.407	04.9	29.56
32		158.388		.396	05.2	29.57
33		158.337		.384	05.6	29.57
34		158.286		.373	05.9	29.57
35		158.235		.361	06.3	29.57
36		158.184		.350	06.6	29.58
37		158.133		.339	07.0	29.58
38		158.083		.327	07.3	29.58
39		158.032		.316	07.7	29.58
40	29.0	157.981	.008	178.304	18° 08.0′	29.59
41		157.930		.293	08.4	29.59
42		157.879		.281	08.7	29.59
43		157.828		.270	09.1	29.60
44		157.778		.259	09.4	29.60
45		157.727		.247	09.8	29.60
46		157.676		.236	10.1	29.60
47		157.625		.224	10.5	29.61
48		157.575		.213	10.8	29.61
49		157.524		.201	11.2	29.61
50	29.1	157.474	.008	178.190	18° 11.5′	29.61
51		157.423		.178	11.9	29.62
52		157.372		.167	12.2	29.62
53		157.322		.155	12.6	29.62
54		157.271		.144	12.9	29.63
55		157.221		.133	13.3	29.63
56		157.170		.121	13.6	29.63
57		157.120		.110	14.0	29.63
58		157.069		.098	14.3	29.64
59		157.019		.087	14.7	29.64
60	29.1	156.969	.008	178.075	18° 15.0′	29.64

65° — Chord for 50-foot Arc = 49.79

M	Ext Feet	Radius Feet	Diff 10″	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	29.1	156.969	.008	178.075	18° 15.0′	29.64
1		156.918		.064	15.4	29.64
2		156.868		.052	15.7	29.65
3		156.818		.041	16.1	29.65
4		156.767		.029	16.5	29.65
5		156.717		.018	16.8	29.66
6		156.667		.006	17.2	29.66
7		156.616		177.995	17.5	29.66
8		156.566		.983	17.9	29.66
9		156.516		.971	18.2	29.67
10	29.2	156.466	.008	177.960	18° 18.6′	29.67
11		156.416		.948	18.9	29.67
12		156.366		.937	19.3	29.68
13		156.316		.925	19.6	29.68
14		156.265		.914	20.0	29.68
15		156.215		.902	20.3	29.68
16		156.165		.891	20.7	29.69
17		156.115		.879	21.0	29.69
18		156.065		.868	21.4	29.69
19		156.015		.856	21.7	29.69
20	29.3	155.966	.008	177.845	18° 22.1′	29.70
21		155.916		.833	22.4	29.70
22		155.866		.822	22.8	29.70
23		155.816		.810	23.1	29.71
24		155.766		.798	23.5	29.71
25		155.716		.787	23.9	29.71
26		155.666		.775	24.2	29.71
27		155.617		.764	24.6	29.72
28		155.567		.752	24.9	29.72
29		155.517		.740	25.3	29.72
30	29.4	155.467	.008	177.729	18° 25.6′	29.73
31		155.418		.717	26.0	29.73
32		155.368		.706	26.3	29.73
33		155.318		.694	26.7	29.73
34		155.269		.682	27.0	29.74
35		155.219		.671	27.4	29.74
36		155.170		.659	27.7	29.74
37		155.120		.648	28.1	29.74
38		155.071		.636	28.4	29.75
39		155.021		.624	28.8	29.75
40	29.5	154.972	.008	177.613	18° 29.2′	29.75
41		154.922		.601	29.5	29.76
42		154.873		.589	29.9	29.76
43		154.823		.578	30.2	29.76
44		154.774		.566	30.6	29.76
45		154.724		.555	30.9	29.77
46		154.675		.543	31.3	29.77
47		154.626		.531	31.6	29.77
48		154.576		.520	32.0	29.78
49		154.527		.508	32.3	29.78
50	29.5	154.478	.008	177.496	18° 32.7′	29.78
51		154.429		.485	33.1	29.78
52		154.379		.473	33.4	29.79
53		154.330		.461	33.8	29.79
54		154.281		.450	34.1	29.79
55		154.232		.438	34.5	29.80
56		154.183		.426	34.8	29.80
57		154.134		.415	35.2	29.80
58		154.085		.403	35.5	29.80
59		154.036		.391	35.9	29.81
60	29.6	153.987	.008	177.380	18° 36.2′	29.81

Area of 100 Ft, and Skew Distances for Widths of 25 Ft

Table VII.—Externals, Radii, Arcs for Tangents of 100 Ft, Deflections

68°						
Chord for 50-foot Arc = 49.76						
M	Ext Feet	Radius Feet	Diff 10″	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	30.6	148.256	.008	175.954	19° 19.4′	30.16
1		148.210		.942	[illegible]	30.16
2		148.163		.930	20.1	[illegible]
3		148.117		.918	20.5	30.16
4		148.070		.906	20.9	30.17
5		[illegible]		[illegible]	21.2	30.17
6		147.977		.881	21.6	30.17
7		147.931		.869	21.9	[illegible]
8		147.885		.857	[illegible]	30.18
9		147.838		.845	22.7	30.18
10	30.7	147.792	.008	175.833	19° 23.0′	30.19
11		[illegible]		.821	23.4	30.19
12		147.699		.809	23.8	30.19
13		147.653		.796	24.1	30.19
14		147.607		.784	24.5	30.20
15		147.561		.772	24.9	30.20
16		147.514		.760	25.2	30.20
17		147.468		.748	25.6	30.21
18		147.422		.736	26.0	30.21
19		147.376		[illegible]	26.3	30.21
20	[illegible]	147.330	.008	175.712	19° 26.7′	30.21
21		147.284		.700	27.0	30.22
22		147.238		.687	27.4	30.22
23		147.192		.675	27.8	30.22
24		147.146		.663	28.1	30.23
25		147.100		.651	28.5	[illegible]
26		147.054		.639	28.9	30.23
27		147.008		.626	29.2	30.24
28		146.962		.614	29.6	30.24
29		146.916		.602	30.0	30.24
30	30.8	146.870	.008	175.590	19° 30.3′	30.24
31		146.824		.578	30.7	30.25
32		146.778		.566	31.1	30.25
33		146.732		.553	31.4	30.25
34		146.686		.541	31.8	30.26
35		146.640		.529	[illegible]	30.26
36		146.595		.517	32.5	30.26
37		146.549		.505	32.9	30.27
38		146.503		.493	33.3	30.27
39		[illegible]		[illegible]	33.6	30.27
40	30.9	146.411	.008	175.468	19° 34.0′	30.27
41		146.366		.456	34.4	30.28
42		146.320		.444	34.7	[illegible]
43		146.274		.431	35.1	30.28
44		146.229		.419	35.5	30.29
45		146.183		.407	35.8	30.29
46		146.137		.395	36.2	30.29
47		146.092		.383	36.6	30.30
48		146.046		.370	36.9	30.30
49		146.001		.358	37.3	30.30
50	31.0	145.955	.008	175.346	19° 37.7′	30.30
51		145.910		.334	38.0	30.31
52		145.864		[illegible]	38.4	30.31
53		145.819		.309	38.8	30.31
54		145.773		.297	39.1	30.32
55		145.728		.285	39.5	30.32
56		145.682		.272	39.9	30.32
57		145.637		.260	40.2	30.33
58		145.592		.248	40.6	30.33
59		145.546		.236	41.0	30.33
60	31.1	145.501	.008	175.223	19° 41.3′	30.34

69°						
Chord for 50-foot Arc = 49.75						
M	Ext Feet	Radius Feet	Diff 10″	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	1	145.501	.008	175.223	19° 41.3′	30.34
1		145.456		.211	41.7	30.34
2		145.410		.199	42.1	30.34
3		145.365		.186	42.5	30.34
4		145.320		.174	42.8	30.35
5		145.274		.162	43.2	30.35
6		145.229		.150	43.6	30.35
7		145.184		.137	43.9	30.36
8		145.139		[illegible]	44.3	30.36
9		145.094		.113	44.7	30.36
10	1	145.049	.008	175.100	19° 45.0′	30.37
11		145.003		.088	45.4	30.37
12		144.958		.076	45.8	30.37
13		144.913		.063	46.1	30.37
14		144.868		.051	46.5	30.38
15		144.823		.039	46.9	30.38
16		144.778		.027	47.2	30.38
17		144.733		.014	47.6	30.39
18		[illegible].688		.002	48.0	30.39
19		144.643		174.990	48.4	30.39
20	2	144.598	.008	174.977	19° 48.7′	30.40
21		144.553		.965	49.1	30.40
22		144.508		.953	49.4	30.40
23		144.463		.940	49.8	30.41
24		144.418		.928	50.2	30.41
25		144.373		.915	50.6	30.41
26		144.329		.903	50.9	30.41
27		144.284		.891	51.3	30.42
28		144.239		.878	51.7	30.42
29		144.194		.866	52.1	30.42
30	3	144.149	.007	174.854	19° 52.4′	30.43
31		144.105		.841	52.8	30.43
32		144.060		.829	53.1	30.43
33		144.015		.816	53.5	30.44
34		143.970		.804	53.9	30.44
35		143.926		.792	54.2	30.44
36		143.881		.779	54.6	30.45
37		143.836		.767	55.0	30.45
38		143.792		.755	55.3	30.45
39		143.747		.742	55.8	30.45
40	4	143.703	.007	174.730	19° 56.1′	30.46
41		143.658		.717	56.5	30.46
42		143.614		.705	56.9	30.46
43		143.569		.693	57.2	30.47
44		143.525		.680	57.6	30.47
45		143.480		.668	58.0	30.47
46		143.436		.655	58.4	30.48
47		143.391		.643	58.7	30.48
48		143.347		.630	59.1	30.48
49		143.302		.618	59.5	30.49
50	5	143.258	[illegible]	174.606	19° 59.8′	30.49
51		143.213		[illegible]	20° 00.2′	30.4[illegible]
52		143.169		.581	00.6	30.4[illegible]
53		143.125		[illegible]	01.0	30.5[illegible]
54		143.080		.556	01.3	30.5[illegible]
55		143.036		[illegible]	01.7	30.5[illegible]
56		142.992		.531	02.1	30.5[illegible]
57		142.947		.519	02.5	30.51
58		142.903		.506	02.8	30.51
59		142.859		.494	03.2	30.52
60	31.5	142.815	.007	174.481	20° 03.6′	30.52

...Arcs of 100 Ft, and Skew Distances for Widths of 25 Ft

70° — Chord for 50-foot Arc = 49.74

M	Ext Feet	Radius Feet	Diff 10″	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	31.5	142.815	.007	174.481	20° 03.6′	30.52
1		142.771		.469	03.9	30.52
2		142.726		.456	04.3	30.53
3		142.682		.444	04.7	30.53
4		142.638		.431	05.1	30.53
5		142.594		.419	05.4	30.53
6		142.550		.406	05.8	30.54
7		142.506		.394	06.2	30.54
8		142.462		.381	06.6	30.54
9		142.418		.369	06.9	30.55
10	31.6	142.374	.007	174.356	20° 07.3′	30.55
11		142.330		.344	07.7	30.55
12		142.286		.331	08.0	30.56
13		142.242		.319	08.4	30.56
14		142.198		.306	08.8	30.56
15		142.154		.294	09.2	30.57
16		142.110		.281	09.5	30.57
17		142.066		.269	09.9	30.57
18		142.022		.256	10.3	30.58
19		141.978		.244	10.7	30.58
20	31.7	141.934	.007	174.231	20° 11.0′	30.58
21		141.890		.219	11.4	30.58
22		141.847		.206	11.8	30.59
23		141.803		.193	12.2	30.59
24		141.759		.181	12.5	30.59
25		141.715		.168	12.9	30.60
26		141.672		.156	13.3	30.60
27		141.628		.143	13.7	30.60
28		141.584		.131	14.0	30.61
29		141.540		.118	14.4	30.61
30	31.8	141.497	.007	174.106	10° 14.8′	30.61
31		141.453		.093	15.2	30.62
32		141.409		.080	15.5	30.62
33		141.366		.068	15.9	30.62
34		141.322		.055	16.3	30.63
35		141.279		.043	16.7	30.63
36		141.235		.030	17.0	30.63
37		141.191		.018	17.4	30.64
38		141.148		.005	17.8	30.64
39		141.104		173.992	18.2	30.64
40	31.9	141.061	.007	173.980	20° 18.5′	30.64
41		141.017		.967	18.9	30.65
42		140.974		.955	19.3	30.65
43		140.931		.942	19.7	30.65
44		140.887		.929	20.0	30.66
45		140.844		.917	20.4	30.66
46		140.800		.904	20.8	30.66
47		140.757		.891	21.2	30.67
48		140.714		.879	21.5	30.67
49		140.670		.866	21.9	30.67
50	31.9	140.627	.007	173.853	20° 22.3′	30.68
51		140.584		.841	22.7	30.68
52		140.540		.828	23.0	30.68
53		140.497		.816	23.4	30.69
54		140.454		.803	23.8	30.69
55		140.411		.790	24.2	30.69
56		140.367		.778	24.6	30.70
57		140.324		.765	24.9	30.70
58		140.281		.752	25.3	30.70

71° — Chord for 50-foot Arc = 49.74

M	Ext Feet	Radius Feet	Diff 10″	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	32.0	140.195	.007	173.727	20° 26.1′	30.71
1		140.152		.714	26.4	30.71
2		140.109		.702	26.8	30.71
3		140.065		.689	27.2	30.72
4		140.022		.676	27.6	30.72
5		139.979		.664	27.9	30.72
6		139.936		.651	28.3	30.73
7		139.893		.638	28.7	30.73
8		139.850		.626	29.1	30.73
9		139.807		.613	29.5	30.74
10	32.1	139.764	.007	173.600	20° 29.8′	30.74
11		139.721		.588	30.2	30.74
12		139.679		.575	30.6	30.75
13		139.636		.562	31.0	30.75
14		139.593		.549	31.3	30.75
15		139.550		.537	31.7	30.76
16		139.507		.524	32.1	30.76
17		139.464		.511	32.5	30.76
18		139.421		.499	32.9	30.77
19		139.379		.486	33.2	30.77
20	32.2	139.336	.007	173.473	20° 33.6′	30.77
21		139.293		.460	34.0	30.78
22		139.250		.448	34.4	30.78
23		139.207		.435	34.8	30.78
24		139.165		.422	35.1	30.79
25		139.122		.409	35.5	30.79
26		139.079		.397	35.9	30.79
27		139.037		.384	36.3	30.79
28		138.994		.371	36.7	30.80
29		138.951		.358	37.0	30.80
30	32.3	138.909	.007	173.346	20° 37.4′	30.80
31		138.866		.333	37.8	30.81
32		138.824		.320	38.2	30.81
33		138.781		.307	38.6	30.81
34		138.738		.294	38.9	30.82
35		138.696		.282	39.3	30.82
36		138.653		.269	39.7	30.82
37		138.611		.256	40.1	30.83
38		138.568		.243	40.5	30.83
39		138.526		.231	40.8	30.83
40	32.3	138.484	.007	173.218	20° 41.2′	30.84
41		138.441		.205	41.6	30.84
42		138.399		.192	42.0	30.84
43		138.356		.179	42.4	30.85
44		138.314		.167	42.7	30.85
45		138.272		.154	43.1	30.85
46		138.229		.141	43.5	30.86
47		138.187		.128	43.9	30.86
48		138.145		.115	44.3	30.86
49		138.102		.102	44.6	30.87
50	32.4	138.060	.007	173.090	20° 45.0′	30.87
51		138.018		.077	45.4	30.87
52		137.976		.064	45.8	30.88
53		137.933		.051	46.2	30.88
54		137.891		.038	46.5	30.88
55		137.849		.025	46.9	30.89
56		137.807		.013	47.3	30.89
57		137.765		.000	47.7	30.89
58		137.722		172.987	48.1	30.90

Table VII.—Externals, Radii, Arcs for Tangents of 100 Ft, Deflections

72°							
Chord for 50-foot Arc = 49.73							
M	Ext Feet	Radius Feet	Diff 10"	Arc Feet	Def Arc 100 Feet		Skew 25 Ft
0	32.5	137.638	.007	172.961	20°	48.8′	30.90
1		137.596		.948		49.2	30.90
2		137.554		.935		49.6	30.91
3		137.512		.923		50.0	30.91
4		137.470		.910		50.4	30.91
5		137.428		.897		50.7	30.92
6		137.386		.884		51.1	30.92
7		137.344		.871		51.5	30.92
8		137.302		.858		51.9	30.93
9		137.260		.845		52.3	30.93
10	32.6	137.218	.007	172.832	20°	52.7′	30.93
11		137.176		.819		53.0	30.94
12		137.134		.806		53.4	30.94
13		137.092		.794		53.8	30.94
14		137.050		.781		54.2	30.95
15		137.009		.768		54.6	30.95
16		136.967		.755		55.0	30.95
17		136.925		.742		55.3	30.96
18		136.883		.729		55.7	30.96
19		136.841		.716		56.1	30.96
20	32.7	136.800	.007	172.703	20°	56.5′	30.97
21		136.758		.690		56.9	30.97
22		136.716		.677		57.3	30.97
23		136.674		.664		57.6	30.98
24		136.633		.651		58.0	30.98
25		136.591		.638		58.4	30.98
26		136.549		.626		58.8	30.99
27		136.508		.613		59.2	30.99
28		136.466		.600		59.6	30.99
29		136.424		.587		59.9′	31.00
30	32.7	136.383	.007	172.574	21°	00.3′	31.00
31		136.341		.561		00.7	31.00
32		136.300		.548		01.1	31.01
33		136.258		.535		01.5	31.01
34		136.217		.522		01.9	31.01
35		136.175		.509		02.3	31.02
36		136.134		.496		02.6	31.02
37		136.092		.483		03.0	31.02
38		136.051		.470		03.4	31.03
39		136.009		.457		03.8	31.03
40	32.8	135.968	.007	172.444	21°	04.2′	31.03
41		135.926		.431		04.6	31.04
42		135.885		.418		04.9	31.04
43		135.843		.405		05.3	31.04
44		135.802		.392		05.7	31.05
45		135.761		.379		06.1	31.05
46		135.719		.366		06.5	31.06
47		135.678		.353		06.9	31.06
48		135.637		.340		07.3	31.06
49		135.595		.327		07.6	31.06
50	32.9	135.554	.007	172.314	21°	08.0′	31.07
51		135.513		.301		08.4	31.07
52		135.472		.288		08.8	31.07
53		135.430		.275		09.2	31.08
54		135.389		.262		09.6	31.08
55		135.348		.249		10.0	31.08
56		135.307		.236		10.4	31.09
57		135.266		.222		10.7	31.09
58		135.224		.209		11.1	31.09
59		135.183		.196		11.5	31.10
60	33.0	135.142	.007	172.183	21°	11.9′	31.10

r Arcs of 100 Ft, and Skew Distances for Widths of 25 Ft

74°					
Chord for 50-foot Arc = 49.70					
Ext Feet	Radius Feet	Diff 10″	Arc Feet	Def Arc 100 Feet	Sk 25
33.5	132.704	.007	171.394	21° 35.3′	31
	132.664		.380	35.7	31
	132.624		.367	36.0	31
	132.584		.354	36.4	31
	132.544		.340	36.8	31
	132.504		.327	37.2	31
	132.464		.314	37.6	31
	132.424		.301	38.0	31
	132.384		.287	38.4	31
	132.344		.274	38.8	31
33.5	132.304	.007	171.261	21° 39.2′	31
	132.264		.247	39.6	31
	[illegible]		.234	40.0	31
	132.184		.221	40.4	31
	132.144		.207	40.8	31
	132.104		.194	41.2	31
	132.064		.181	41.5	31
	132.024		.168	41.9	31
	131.984		.154	42.3	31
	131.944		.141	42.7	31
33.6	131.904	.007	171.128	21° 43.1′	31
	131.865		.114	43.5	31
	131.825		.101	43.9	31
	131.785		.088	44.3	31
	131.745		.074	44.7	31
	[illegible]		[illegible]	45.1	31
	131.666		.048	45.5	31
	131.626		.034	45.9	31
	131.586		.021	46.3	31
	131.546		[illegible]	46.7	31
33.7	131.507	.007	170.994	21° 47.1′	31
	131.467		.981	47.5	31
	131.427		.967	47.9	31
	131.388		.954	48.2	31
	131.348		.941	48.6	31
	131.308		[illegible]	49.0	31
	131.269		.914	49.4	31
	131.229		.900	49.8	31
	[illegible]		.887	50.2	31
	131.150		.874	50.6	31
33.8	131.110	.007	170.860	21° 51.0′	31
	[illegible]		.847	51.4	31
	131.031		.834	51.8	31
	130.992		.820	52.2	31
	130.952		.807	52.6	31
	130.913		.793	53.0	31
	130.873		.780	53.4	31
	130.834		[illegible]	53.8	31
	130.795		.753	54.2	31
	130.755		.740	[illegible]	31
33.9	130.716	.007	170.726	21° 55.0′	31
	130.676		.713	55.4	31
	130.637		.699	55.8	31
	130.598		.686	56.2	31
	130.558		[illegible]	56.6	31
	130.519		[illegible]	57.0	31
	130.480		.646	57.4	31
	130.440		.632	57.7	31
	[illegible]		.619	58.1	31

Table VII.—Externals, Radii, Arcs for Tangents of 100 Ft, Deflections

76°

Chord for 50-foot Arc = 49.68

M	Ext Feet	Radius Feet	Diff 10″	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	34.4	127.994	.006	169.778	22° 22.9′	31.73
1		127.956		.764	23.3	31.73
2		127.917		.751	23.7	31.73
3		127.879		.737	24.1	31.74
4		127.841		.723	24.5	31.74
5		127.802		.709	24.9	31.74
6		127.764		.696	25.3	31.75
7		127.726		.682	25.8	31.75
8		127.688		.668	26.2	31.75
9		127.649		.655	26.6	31.76
10	34.5	127.611	.006	169.641	22° 27.0′	31.76
11		127.573		.627	27.4	31.77
12		127.535		.614	27.8	31.77
13		127.497		.600	28.2	31.77
14		127.458		.586	28.6	31.78
15		127.420		.572	29.0	31.78
16		127.382		.559	29.4	31.76
17		127.344		.545	29.8	31.79
18		127.306		.531	30.2	31.79
19		127.268		.518	30.6	31.79
20	34.6	127.230	.006	169.504	22° 31.0′	31.80
21		127.191		.490	31.4	31.80
22		127.153		.476	31.8	31.81
23		127.115		.463	32.2	31.81
24		127.077		.449	32.6	31.81
25		127.039		.435	33.0	31.82
26		127.001		.421	33.4	31.82
27		126.963		.408	33.8	31.82
28		126.925		.394	34.2	31.83
29		126.887		.380	34.6	31.83
30	34.7	126.849	.006	169.366	22° 35.1′	31.83
31		126.811		.352	35.5	31.84
32		126.774		.339	35.9	31.84
33		126.736		.325	36.3	31.85
34		126.698		.311	36.7	31.85
35		126.660		.297	37.1	31.85
36		126.622		.284	37.5	31.86
37		126.584		.270	37.9	31.86
38		126.546		.256	38.3	31.86
39		126.508		.242	38.7	31.87
40	34.8	126.471	.006	169.229	22° 39.1′	31.87
41		126.433		.215	39.5	31.87
42		126.395		.201	39.9	31.88
43		126.357		.187	40.3	31.88
44		126.320		.173	40.7	31.89
45		126.282		.159	41.1	31.89
46		126.244		.145	41.5	31.89
47		126.206		.132	42.0	31.90
48		126.169		.118	42.4	31.90
49		126.131		.104	42.8	31.90
50	34.8	126.093	.006	169.090	22° 43.2′	31.91
51		126.056		.076	43.6	31.91
52		126.018		.063	44.0	31.91
53		125.980		.049	44.4	31.92
54		125.943		.035	44.8	31.92
55		125.905		.021	45.2	31.93
56		125.867		.007	45.6	31.93
57		125.830		168.993	46.0	31.93
58		125.792		.979	46.4	31.94
59		125.755		.966	46.8	31.94
60	34.9	125.717	.006	168.952	22° 47.3′	31.94

[illegible]

Chord for 50-foot Arc = 49.67

M	Ext Feet	Radius Feet	Diff 10″	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	34.9	125.717	.006	168.952	22° 47.3′	31.94
1		125.680		.938	47.7	31.95
2		125.642		.924	48.1	31.95
3		125.605		.910	48.5	31.96
4		125.567		.896	48.9	31.96
5		125.530		.882	49.3	31.96
6		125.492		.868	49.7	31.97
7		125.455		.855	50.1	31.97
8		125.417		.841	50.5	31.97
9		125.380		.827	50.9	31.98
10	35.0	125.343	.006	168.813	22° 51.3′	31.98
11		125.305		.799	51.8	31.99
12		125.268		.785	52.2	31.99
13		125.231		.771	52.6	31.99
14		125.193		.757	53.0	32.00
15		125.156		.743	53.4	32.00
16		125.118		.729	53.8	32.00
17		125.081		.716	54.2	32.01
18		125.044		.702	54.6	32.01
19		125.007		.688	55.0	32.01
20	35.1	124.969	.006	168.674	22° 55.4′	32.02
21		124.932		.660	55.8	32.02
22		124.895		.646	56.3	32.03
23		124.858		.632	56.7	32.03
24		124.820		.618	57.1	32.03
25		124.783		.604	57.5	32.04
26		124.746		.590	57.9	32.04
27		124.709		.576	58.3	32.04
28		124.672		.562	58.7	32.05
29		124.635		.548	59.1	32.05
30	35.2	124.597	.006	168.534	22° 59.5′	32.06
31		124.560		.520	23° 00.0′	32.06
32		124.523		.506	00.4	32.06
33		124.486		.492	00.8	32.07
34		124.449		.478	01.2	32.07
35		124.412		.464	01.6	32.07
36		124.375		.450	02.0	32.08
37		124.338		.436	02.4	32.08
38		124.301		.422	02.8	32.09
39		124.264		.408	03.2	32.09
40	35.2	124.227	.006	168.394	23° 03.7′	32.09
41		124.190		.380	04.1	32.10
42		124.153		.366	04.5	32.10
43		124.116		.352	04.9	32.10
44		124.079		.338	05.3	32.11
45		124.042		.324	05.7	32.11
46		124.005		.310	06.1	32.12
47		123.968		.296	06.5	32.12
48		123.931		.282	07.0	32.12
49		123.894		.268	07.4	32.13
50	35.3	123.858	.006	168.254	23° 07.8′	32.13
51		123.821		.240	08.2	32.13
52		123.784		.226	08.6	32.14
53		123.747		.212	09.0	32.14
54		123.710		.198	09.4	32.15
55		123.674		.184	09.8	32.15
56		123.617		.170	10.3	32.16
57		123.600		.156	10.7	32.16
58		123.563		.142	11.1	32.16
59		123.526		.128	11.5	32.17
60	35.4	123.490	.006	168.114	23° 11.9′	32.17

for Arcs of 100 Ft, and Skew Distances for Widths of 25 Ft

78°

Chord for 50-foot Arc = 49.66

M	Ext Feet	Radius Feet	Diff 10″	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	35.4	123.490	.006	168.114	23° 11.9′	32.17
1		123.453		.099	12.3	32.17
2		123.416		.085	12.7	32.18
3		123.380		.071	13.2	32.18
4		123.343		.057	13.6	32.18
5		123.306		.043	14.0	32.19
6		123.270		.029	14.4	32.19
7		123.233		.015	14.8	32.20
8		123.196		.001	15.2	32.20
9		123.160		167.937	15.6	32.20
10	35.5	123.123	.006	167.973	23° 16.1′	32.21
11		123.087		.958	16.5	32.21
12		123.050		.944	16.9	32.21
13		123.013		.930	17.3	32.22
14		122.977		.916	17.7	32.22
15		122.940		.902	18.1	32.23
16		122.904		.888	18.6	32.23
17		122.867		.874	19.0	32.23
18		122.831		.860	19.4	32.24
19		122.794		.846	19.8	32.24
20	35.6	122.758	.006	167.831	23° 20.2′	32.25
21		122.721		.817	20.6	32.25
22		122.685		.803	21.0	32.25
23		122.649		.789	21.5	32.26
24		122.612		.775	21.9	32.26
25		122.576		.761	22.3	32.26
26		122.539		.746	22.7	32.27
27		122.503		.732	23.1	32.27
28		122.467		.718	23.5	32.28
29		122.430		.704	24.0	32.28
30	35.7	122.394	.006	167.690	23° 24.4′	32.28
31		122.358		.675	24.8	32.29
32		122.321		.661	25.2	32.29
33		122.285		.647	25.6	32.29
34		122.249		.633	26.0	32.30
35		122.212		.619	26.5	32.30
36		122.176		.605	26.9	32.31
37		122.140		.590	27.3	32.31
38		122.104		.576	27.7	32.31
39		122.067		.562	28.1	32.32
40	35.7	122.031	.006	167.548	23° 28.6′	32.32
41		121.995		.534	29.0	32.33
42		121.959		.519	29.4	32.33
43		121.923		.505	29.8	32.33
44		121.887		.491	30.2	32.34
45		121.850		.477	30.6	32.34
46		121.814		.462	31.1	32.34
47		121.778		.448	31.5	32.35
48		121.742		.434	31.9	32.35
49		121.706		.420	32.3	32.36
50	35.8	121.670	.006	167.405	23° 32.7′	32.36
51		121.634		.391	33.2	32.36
52		121.598		.377	33.6	32.37
53		121.562		.363	34.0	32.37
54		121.526		.348	34.4	32.38
55		121.490		.334	34.8	32.38
56		121.454		.320	35.3	32.38
57		121.418		.306	35.7	32.39
58		121.382		.291	36.1	32.39
59		121.346		.277	36.5	32.40
60	35.9	121.310	.006	167.263	23° 36.9′	32.40

79°

Chord for 50-foot Arc = 49.65

M	Ext Feet	Radius Feet	Diff 10″	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	35.9	121.310	.006	167.263	23° 36.9′	32.40
1		121.274		.249	37.4	32.40
2		121.238		.234	37.8	32.41
3		121.202		.220	38.2	32.41
4		121.166		.206	38.6	32.41
5		121.130		.191	39.0	32.42
6		121.094		.177	39.5	32.42
7		121.058		.163	39.9	32.43
8		121.023		.149	40.3	32.43
9		120.987		.134	40.7	32.43
10	36.0	120.951	.006	167.120	23° 41.1′	32.44
11		120.915		.106	41.6	32.44
12		120.879		.091	42.0	32.45
13		120.843		.077	42.4	32.45
14		120.808		.063	42.8	32.45
15		120.772		.048	43.2	32.46
16		120.736		.034	43.7	32.46
17		120.700		.020	44.1	32.47
18		120.665		.005	44.5	32.47
19		120.629		166.991	44.9	32.47
20	36.1	120.593	.006	166.977	23° 45.3′	32.48
21		120.558		.962	45.8	32.48
22		120.522		.948	46.2	32.49
23		120.486		.934	46.6	32.49
24		120.451		.919	47.0	32.49
25		120.415		.905	47.5	32.50
26		120.379		.891	47.9	32.50
27		120.344		.876	48.3	32.50
28		120.308		.862	48.7	32.51
29		120.273		.847	49.1	32.51
30	36.2	120.237	.006	166.833	23° 49.6′	32.52
31		120.201		.819	50.0	32.52
32		120.166		.804	50.4	32.52
33		120.130		.790	50.8	32.53
34		120.095		.775	51.3	32.53
35		120.059		.761	51.7	32.54
36		120.024		.747	52.1	32.54
37		119.988		.732	52.5	32.54
38		119.953		.718	53.0	32.55
39		119.917		.704	53.4	32.55
40	36.2	119.882	.006	166.689	23° 53.8′	32.56
41		119.846		.675	54.2	32.56
42		119.811		.660	54.7	32.56
43		119.776		.646	55.1	32.57
44		119.740		.631	55.5	32.57
45		119.705		.617	55.9	32.58
46		119.669		.602	56.4	32.58
47		119.634		.588	56.8	32.58
48		119.599		.574	57.2	32.59
49		119.563		.559	57.6	32.59
50	36.3	119.528	.006	166.545	23° 58.1′	32.60
51		119.493		.530	58.5	32.60
52		119.457		.516	58.9	32.60
53		119.422		.501	59.3	32.61
54		119.387		.487	59.8	32.61
55		119.351		.472	24° 00.2′	32.62
56		119.316		.458	00.6	32.62
57		119.281		.444	01.0	32.62
58		119.246		.429	01.5	32.63
59		119.211		.415	01.9	32.63
60	36.4	119.175	.006	166.400	24° 02.3′	32.64

Table VII.—Externals, Radii, Arcs for Tangents of 100 Ft, Deflections

Chord for 50-foot Arc = 49.64						
M	Ext Feet	Radius Feet	Diff 10″	Arc Feet	Def Arc 100 Feet	Shew 25 Ft
0	36.4	119.175	.006	166.400	24° 02.3′	32.64
1		119.140		.385	02.7	32.64
2		119.105		.371	03.2	32.64
3		119.070		.357	03.6	32.65
4		119.035		[illegible]	04.0	32.65
5		118.999		.328	04.4	32.66
6		118.964		.313	04.9	32.66
7		118.929		.299	05.3	32.66
8		118.894		.284	05.7	32.67
9		118.859		.270	06.1	32.67
10	36.5	118.824	.006	166.255	24° 06.6′	32.68
11		118.789		.240	07.0	32.68
12		118.754		.226	07.4	32.68
13		118.719		.211	07.9	32.69
14		118.684		.197	08.3	32.69
15		118.649		.182	08.7	32.70
16		118.614		.168	09.1	32.70
17		118.579		153	09.6	32.70
18		118.544		.139	10.0	32.71
19		118.509		.124	10.4	32.71
20	36.6	118.474	.006	166.110	24° 10.8′	32.72
21		118.439		.095	11.3	32.72
22		118.404		.081	11.7	32.72
23		118.369		.066	12.1	32.73
24		118.334		[illegible]	12.6	32.73
25		118.299		.037	13.0	32.74
26		118.264		[illegible]	13.4	32.74
27		118.229		.008	13.8	32.74
28		118.194		165.993	14.3	32.75
29		118.160		.979	14.7	32.75
30	36.6	118.125	.006	165.964	24° 15.1′	32.76
31		118.090		[illegible]	15.6	32.76
32		118.055		.935	16.0	32.76
33		118.020		.920	16.4	32.77
34		117.986		.906	16.9	32.77
35		117.951		.891	17.3	32.78
36		117.916		.876	17 7	32.78
37		117.881		.862	18.1	32.78
38		117.846		.847	18.6	32.79
39		117.812		.833	19.0	32.79
40	36.7	117.777	.006	165.818	24° 19.4′	32.80
41		117.742		.803	19.9	32.80
42		117.708		.789	20.3	32.80
43		117.673		.774	20.7	32.81
44		117.638		.759	21.2	32.81
45		117.604		[illegible]	[illegible]	32.82
46		117.569		.730	22.0	32.82
47		117.534		[illegible]	22.4	32.82
48		117.500		[illegible]	22.9	32.83
49		117.465		.686	23.3	32.83
50	36.8	117.430	.006	165.672	24° 23.7′	32.84
51		117.396		.657	24.2	32.84
52		[illegible]		.642	24.6	32.84
53		117.327		.628	25.0	32.85
54		117.292		.613	25.5	32.85
55		117.257		.598	25.9	32.86
56		117.223		.584	26.3	32.86
57		117.188		.569	26.8	32.86
58		117.154		.554	27.2	[illegible]
59		117.119		.540	27.6	32.87
60	36.9	117.085	.006	165.525	24° 28.1′	32.88

Chord for 50-foot Arc = 49.62						
M	Ext Feet	Radius Feet	Diff 10″	[illegible] Feet	Def Arc 100 Feet	Shew 25 F
0	36.9	117.085	.006	165.525	24° 28.1′	32.88
1		117.050		.510	28.5	32.88
2		117.016		.496	28.9	32.89
3		116.982		.481	29.4	32.89
4		116.947		.466	29.8	32.89
5		116.913		.451	30.2	32.90
6		116.878		.437	30.7	32.90
7		116.844		.422	31.1	32.91
8		116.809		.407	31.5	32.91
9		116.775		[illegible]	32.0	32.91
10	37.0	116.741	[illegible]	165.378	24° 32.4′	[illegible]
11		116.706		.363	32.8	32.92
12		116.672		[illegible]	33.3	[illegible]
13		116.638		.334	33.7	32.93
14		116.603		.319	34.1	32.93
15		116.569		.304	34.6	32.94
16		116.535		.289	35.0	32.94
17		116.500		.275	35.4	32.95
18		116.466		.260	35.9	32.95
19		116.432		.245	36.3	32.96
20	37.1	116.398	.006	165.230	24° 36.7′	32.96
21		[illegible]		.216	37.2	32.96
22		116.329		.201	37.6	32.97
23		116.295		.186	38.0	32.97
24		116.261		171	38.5	32.98
25		116.227		.156	38.9	32.98
26		116.192		.142	39.3	32.98
27		116.158		.127	39.8	32.99
28		116.124		.112	40.2	32.99
29		116.090		.097	40.6	33.00
30	37.1	116.056	.006	165.083	24° 41.1′	33.00
31		116.022		.068	41.5	33.00
32		115.987		.053	41.9	33.01
33		115.953		.038	42.4	33.01
34		115.919		.023	42.8	33.02
35		115.885		.009	43.3	33.02
36		115.851		164.994	43.7	[illegible]
37		115.817		.979	44.1	33.03
38		115.783		.964	44.6	33.03
39		115.749		.949	45.0	33.04
40	37.2	[illegible]	.006	164.935	24° 45.4′	33.04
41		115.681		.920	45.9	33.05
42		115.647		.905	46.3	33.05
43		115.613		.890	46.7	33.05
44		115.579		.875	47.2	33.06
45		115.545		.860	47.6	33.06
46		115.511		.845	48.1	33.07
47		115.477		.831	48.5	33.07
48		115.443		.816	48.9	33.07
49		115.409		.801	49.4	33.08
50	37.3	115.375	.006	164.786	24° 49.8′	[illegible]
51		115.341		771	50.2	33.09
52		115.308		.756	50.7	33.09
53		115.274		.741	51.1	33.10
54		115.240		.726	51.6	33.10
55		115.206		.712	52.0	33.10
56		115.172		.697	52.4	33.11
57		115.138		.682	52.9	33.11
58		115.104		.667	53.3	33.12
59		115.071		.652	[illegible]	33.12
60	37.4	115.037	.006	164.637	24° 54.3′	33.12

for Arcs of 100 Ft, and Skew Distances for Widths of 25 Ft

	37°						38°					
	Chord for 50-foot Arc = 49.61						Chord for 50-foot Arc = [illegible]					
M	Ext Feet	Radius Feet	Diff 10″	Arc Feet	Def Arc 100 Feet	Sk 25	t et	Radius Feet	Diff 10″	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	37.4	115.037	.006	[illegible]	24° 54.2′	33.	9	113.029	.006	163.737	25° 20.7′	33.38
1		115.003		.622	[illegible]	33.		112.996		.722	21.2	33.38
2		114.969		.607	55.1	33.		112.963		.707	21.6	33.39
3		114.935		.592	55.5	33.		112.930		.692	22.1	33.39
4		114.902		.577	56.0	33.		112.897		.677	22.5	33.40
5		114.868		.563	56.4	33.		112.864		.661	23.0	33.40
6		114.834		.548	56.8	33.		112.831		.646	23.4	33.41
7		114.801		.533	57.3	33.		112.798		.631	23.9	33.41
8		114.767		.518	57.7	33.		112.765		.616	24.3	33.41
9		114.733		.503	58.1	33.		112.732		.601	24.7	33.42
10	37.5	114.699	.006	164.488	24° 58.6′	33.	0	112.699	.006	163.586	25° 25.2′	33.42
11		114.666		.473	59.0	33.		112.666		.571	25.6	33.43
12		114.632		[illegible]	59.5	33.		112.633		.555	26.1	33.43
13		114.598		.443	59.9	33.		112.600		.540	26.5	33.44
14		114.565		.428	25° 00.4	33.		112.567		.525	27.0	33.44
15		114.531		.413	00.8	33.		112.534		.510	27.4	33.44
16		114.498		.398	01.2	33.		112.501		[illegible]	27.9	33.45
17		114.464		.383	[illegible]	33.		112.468		.480	28.3	33.45
18		114.430		.368	02.1	33.		112.435		.464	28.8	33.46
19		114.397		.354	02.6	33.		112.402		.449	29.2	33.46
20	37.6	114.363	.006	164.339	25° 03.0′	33.	1	112.369	.006	[illegible]	25° 29.7′	33.47
21		114.330		[illegible]	03.4	33.		112.336		.419	30.1	33.47
22		114.296		.309	03.9	33.		112.303		.404	30.6	33.47
23		114.263		.294	04.3	33.		112.270		.389	31.0	33.48
24		114.229		.279	04.8	33.		112.238		.373	[illegible]	33.48
25		114.196		.264	05.2	33.		112.205		.358	31.9	33.49
26		114.162		.249	05.6	33.		112.172		.343	32.4	33.49
27		114.129		.234	06.1	33.		112.139		.328	32.8	33.50
28		114.095		.219	06.5	33.		112.106		.313	33.3	33.50
29		114.062		.204	07.0	33.		112.073		.297	33.7	33.51
30	37.6	114.028	.006	164.189	25° 07.4′	33.	1	112.041	.006	163.282	25° 34.2′	33.51
31		113.995		.174	07.9	33.		112.008		.267	34.6	33.51
32		113.961		.159	08.3	33.		[illegible]		.252	35.1	33.52
33		113.928		.144	08.7	33.		[illegible]		.236	35.5	33.52
34		113.894		.129	09.2	33.		111.909		.221	36.0	33.53
35		113.861		.114	09.6	33.		111.877		[illegible]	36.4	33.53
36		113.828		.099	10.1	33.		111.844		.191	36.9	33.54
37		113.794		.084	10.5	33.		111.811		.176	37.3	33.54
38		113.761		.069	11.0	33.		[illegible]		.160	37.8	33.54
39		113.727		.054	11.4	33.		111.746		.145	38.2	33.55
40	37.7	113.694	.006	164.039	25° 11.8′	33.	2	111.713	.006	163.130	25° 38.6′	33.55
41		113.661		.023	12.3	33.		111.680		.115	39.1	33.56
42		113.627		.008	12.7	33.		111.648		.099	39.6	33.56
43		113.594		[illegible]	[illegible]	33.		111.615		.084	40.0	33.57
44		113.561		.978	13.6	33.		111.582		.069	40.5	33.57
45		113.528		.963	14.1	33.		111.550		.054	40.9	33.57
46		113.494		.948	14.5	33.		111.517		.038	41.4	33.58
47		113.461		.933	14.9	[illegible]		111.484		.023	41.8	33.58
48		113.428		.918	15.4	33.		111.452		.008	[illegible]	33.59
49		113.394		.903	[illegible]	33.		111.419		162.992	42.7	33.59
50	37.8	113.361	[illegible]	163.888	25° 16.3′	33.	3	111.387	.006	162.977	25° 43.2′	33.60
51		113.328		.873	16.7	33.		111.354		.962	[illegible]	33.60
52		113.295		.858	17.2	33.		111.321		.947	44.1	33.61
53		113.262		.843	17.6	33.		111.289		.931	44.5	33.61
54		113.228		.828	18.1	33.		111.256		.916	45.0	33.61
55		113.195		.812	18.5	33.		111.224		.901	45.4	33.62
56		[illegible]		.797	18.9	33.		111.191		.885	45.9	33.62
57		113.129		[illegible]	19.4	33.		111.159		.870	46.3	33.63
58		113.096		.767	19.8	33.		111.126		.855	[illegible]	33.63
59		113.063		.752	20.3	33.		111.094		.840	47.2	33.64
60	37.9	113.029	.006	163.737	25° 20.7′	33.	4	111.061	.006	162.824	25° 47.7′	33.64

Table VII.—Externals, Radii, Arcs for Tangents of 100 Ft, Deflections

84°						
Chord for 50-foot Arc = 49.58						
M	Ext Feet	Radius Feet	Diff 10″	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	38.4	111.061	.005	162.824	25° 47.7′	33.64
1		111.029		.809	48.1	33.65
2		110.996		.794	48.6	33.65
3		110.964		.778	49.0	33.65
4		110.931		.763	49.5	33.66
5		110.899		.748	49.9	33.66
6		110.867		.732	50.4	33.67
7		110.834		.717	50.9	33.67
8		110.802		.701	51.3	33.68
9		110.769		.686	51.8	33.68
10	38.5	110.737	.005	162.671	25° 52.2′	33.68
11		110.705		.655	52.7	33.69
12		110.672		.640	53.1	33.69
13		110.640		.625	53.6	33.70
14		110.608		.609	54.0	33.70
15		110.575		.594	54.5	33.71
16		110.543		.579	54.9	33.71
17		110.511		.563	55.4	33.72
18		110.478		.548	55.8	33.72
19		110.446		.533	56.3	33.72
20	38.6	110.414	.005	162.517	25° 56.8′	33.73
21		110.381		.502	57.2	33.73
22		110.349		.486	57.7	33.74
23		110.317		.471	58.1	33.74
24		110.285		.456	58.6	33.75
25		110.252		.440	59.0	33.75
26		110.220		.425	59.5	33.76
27		110.188		.409	59.9	33.76
28		110.156		.394	26° 00.4′	33.76
29		110.124		.378	00.9	33.77
30	38.6	110.091	.005	162.363	26° 01.3′	33.77
31		110.059		.348	01.8	33.78
32		110.027		.332	02.2	33.78
33		109.995		.317	02.7	33.79
34		109.963		.301	03.1	33.79
35		109.931		.286	03.6	33.80
36		109.899		.270	04.1	33.80
37		109.866		.255	04.5	33.81
38		109.834		.240	05.0	33.81
39		109.802		.224	05.4	33.81
40	38.7	109.770	.005	162.209	26° 05.9′	33.82
41		109.738		.193	06.3	33.82
42		109.706		.178	06.8	33.83
43		109.674		.162	07.2	33.83
44		109.642		.147	07.7	33.84
45		109.610		.131	08.2	33.84
46		109.578		.116	08.6	33.85
47		109.546		.100	09.1	33.85
48		109.514		.085	09.5	33.85
49		109.482		.069	10.0	33.86
50	38.8	109.450	.005	162.054	26° 10.5′	33.86
51		109.418		.038	10.9	33.87
52		109.386		.023	11.4	33.87
53		109.354		.007	11.8	33.88
54		109.322		161.992	12.3	33.88
55		109.290		.976	12.8	33.89
56		109.258		.961	13.2	33.89
57		109.227		.945	13.7	33.89
58		109.195		.930	14.1	33.90
59		109.163		.914	14.6	33.90
60	38.9	109.131	.005	161.899	26° 15.1′	33.91

85°						
Chord for 50-foot Arc = 49.56						
M	Ext Feet	Radius Feet	Diff 10″	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	38.9	109.131	.005	161.899	26° 15.1′	33.91
1		109.099		.883	15.5	33.91
2		109.067		.868	16.0	33.92
3		109.035		.852	16.4	33.92
4		109.003		.837	16.9	33.93
5		108.972		.821	17.4	33.93
6		108.940		.806	17.8	33.94
7		108.908		.790	18.3	33.94
8		108.876		.774	18.7	33.94
9		108.844		.759	19.2	33.95
10	39.0	108.813	.005	161.743	26° 19.7′	33.95
11		108.781		.728	20.1	33.96
12		108.749		.712	20.6	33.96
13		108.717		.697	21.0	33.97
14		108.686		.681	21.5	33.97
15		108.654		.665	22.0	33.98
16		108.622		.650	22.4	33.98
17		108.590		.634	22.9	33.99
18		108.559		.619	23.4	33.99
19		108.527		.603	23.8	33.99
20	39.1	108.496	.005	161.588	26° 24.3′	34.00
21		108.464		.572	24.7	34.00
22		108.432		.556	25.2	34.01
23		108.401		.541	25.7	34.01
24		108.369		.525	26.1	34.02
25		108.337		.509	26.6	34.02
26		108.306		.494	27.1	34.03
27		108.274		.478	27.5	34.03
28		108.243		.463	28.0	34.04
29		108.211		.447	28.4	34.04
30	39.1	108.179	.005	161.431	26° 28.9′	34.04
31		108.148		.416	29.4	34.05
32		108.116		.400	29.8	34.05
33		108.085		.384	30.3	34.06
34		108.053		.369	30.8	34.06
35		108.022		.353	31.2	34.07
36		107.990		.337	31.7	34.07
37		107.959		.322	32.2	34.08
38		107.927		.306	32.6	34.08
39		107.896		.291	33.1	34.09
40	39.2	107.864	.005	161.275	26° 33.6′	34.09
41		107.833		.259	34.0	34.10
42		107.801		.243	34.5	34.10
43		107.770		.228	34.9	34.10
44		107.738		.212	35.4	34.11
45		107.707		.196	35.9	34.11
46		107.676		.181	36.3	34.12
47		107.644		.165	36.8	34.12
48		107.613		.149	37.3	34.13
49		107.581		.134	37.7	34.13
50	39.3	107.550	.005	161.118	26° 38.2′	34.14
51		107.519		.102	38.7	34.14
52		107.487		.086	39.1	34.15
53		107.456		.071	39.6	34.15
54		107.425		.055	40.1	34.16
55		107.393		.039	40.5	34.16
56		107.362		.024	41.0	34.16
57		107.331		.008	41.5	34.17
58		107.299		160.992	41.9	34.17
59		107.268		.976	42.4	34.18
60	39.4	107.237	.005	160.961	26° 42.9′	34.18

for Arcs of 100 Ft, and Skew Distances for Widths of 25 Ft

86° — Chord for 50-foot Arc = 49.55

M	Ext Feet	Radius Feet	Diff 10″	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	39.4	107.237	.005	160.961	26° 42.9′	34.18
1		107.206		.945	43.3	34.19
2		107.174		.929	43.8	34.19
3		107.143		.913	44.3	34.20
4		107.112		.898	44.7	34.20
5		107.081		.882	45.2	34.21
6		107.049		.866	45.7	34.21
7		107.018		.850	46.2	34.22
8		106.987		.835	46.6	34.22
9		106.956		.819	47.1	34.23
10	39.5	106.926	.005	160.803	26° 47.6′	34.23
11		106.893		.787	48.0	34.23
12		106.862		.771	48.5	34.24
13		106.831		.756	49.0	34.24
14		106.800		.740	49.4	34.25
15		106.769		.724	49.9	34.25
16		106.738		.708	50.4	34.26
17		106.707		.693	50.8	34.26
18		106.676		.677	51.3	34.27
19		106.644		.661	51.8	34.27
20	39.6	106.613	.005	160.645	26° 52.2′	34.28
21		106.582		.629	52.7	34.28
22		106.551		.614	53.2	34.29
23		106.520		.598	53.7	34.29
24		106.489		.582	54.1	34.30
25		106.458		.566	54.6	34.30
26		106.427		.550	55.1	34.30
27		106.396		.534	55.5	34.31
28		106.365		.518	56.0	34.31
29		106.334		.503	56.5	34.32
30	39.6	106.303	.005	160.487	26° 57.0′	34.32
31		106.272		.471	57.4	34.33
32		106.241		.455	57.9	34.33
33		106.210		.439	58.4	34.34
34		106.179		.423	58.8	34.34
35		106.148		.407	59.3	34.35
36		106.117		.392	59.8	34.35
37		106.087		.376	27° 00.3′	34.36
38		106.056		.360	00.7	34.36
39		106.025		.344	01.2	34.37
40	39.7	105.994	.005	160.328	27° 01.7′	34.37
41		105.963		.312	02.1	34.37
42		105.932		.296	02.6	34.38
43		105.901		.280	03.1	34.38
44		105.870		.265	03.6	34.39
45		105.839		.249	04.0	34.39
46		105.809		.233	04.5	34.40
47		105.778		.217	05.0	34.40
48		105.747		.201	05.5	34.41
49		105.716		.185	05.9	34.41
50	39.8	105.685	.005	160.169	27° 06.4′	34.42
51		105.655		.153	06.9	34.42
52		105.624		.137	07.4	34.43
53		105.593		.121	07.8	34.43
54		105.562		.105	08.3	34.44
55		105.532		.089	08.8	34.44
56		105.501		.073	09.3	34.45
57		105.470		.058	09.7	34.45
58		105.439		.042	10.2	34.46
59		105.409		.026	10.7	34.46
60	39.9	105.378	.005	160.010	27° 11.1′	34.46

87° — Chord for 50-foot Arc = 49.53

M	Ext Feet	Radius Feet	Diff 10″	Arc Feet	Def Arc 100 Feet	Skew 25 Ft
0	39.9	105.378	.005	160.010	27° 11.1′	34.46
1		105.347		159.994	11.6	34.47
2		105.317		.978	12.1	34.47
3		105.286		.962	12.6	34.48
4		105.255		.946	13.1	34.48
5		105.225		.930	13.5	34.49
6		105.194		.914	14.0	34.49
7		105.163		.898	14.5	34.50
8		105.133		.882	15.0	34.50
9		105.102		.866	15.4	34.51
10	40.0	105.072	.005	159.850	27° 15.9′	34.51
11		105.041		.834	16.4	34.52
12		105.010		.818	16.9	34.52
13		104.980		.802	17.3	34.53
14		104.949		.786	17.8	34.53
15		104.919		.770	18.3	34.54
16		104.888		.754	18.8	34.54
17		104.858		.738	19.2	34.55
18		104.827		.722	19.7	34.55
19		104.796		.706	20.2	34.56
20	40.1	104.766	.005	159.690	27° 20.7′	34.56
21		104.735		.674	21.2	34.57
22		104.705		.658	21.6	34.57
23		104.674		.642	22.1	34.57
24		104.644		.626	22.6	34.58
25		104.614		.610	23.1	34.58
26		104.583		.594	23.5	34.59
27		104.553		.578	24.0	34.59
28		104.522		.561	24.5	34.60
29		104.492		.545	25.0	34.60
30	40.1	104.461	.005	159.529	27° 25.5′	34.61
31		104.431		.513	25.9	34.61
32		104.401		.497	26.4	34.62
33		104.370		.481	26.9	34.62
34		104.340		.465	27.4	34.63
35		104.309		.449	27.9	34.63
36		104.279		.433	28.3	34.64
37		104.249		.417	28.8	34.64
38		104.218		.401	29.3	34.65
39		104.188		.385	29.8	34.65
40	40.2	104.158	.005	159.369	27° 30.3′	34.66
41		104.127		.353	30.7	34.66
42		104.097		.336	31.2	34.67
43		104.067		.320	31.7	34.67
44		104.036		.304	32.2	34.68
45		104.006		.288	32.7	34.68
46		103.976		.272	33.1	34.69
47		103.946		.256	33.6	34.69
48		103.915		.240	34.1	34.70
49		103.885		.223	34.6	34.70
50	40.3	103.855	.005	159.207	27° 35.1′	34.71
51		103.825		.191	35.6	34.71
52		103.794		.175	36.0	34.72
53		103.764		.159	36.5	34.72
54		103.734		.143	37.0	34.72
55		103.704		.127	37.5	34.73
56		103.674		.111	38.0	34.73
57		103.643		.094	38.4	34.74
58		103.613		.078	38.9	34.74
59		103.583		.062	39.4	34.75
60	40.4	103.553	.005	159.046	27° 39.9′	34.75

Table VII.—Externals, Radii, Arcs for Tangents of 100 Ft, Deflections

88°								89°							
Chord for 50-foot Arc = 49.52								Chord for 50-foot Arc = 49.50							
M	Ext Feet	Radius Feet	Diff 10″	Arc Feet	Def Arc 100 Feet	Skew 25 Ft		M	E F		ff ″	Arc Feet	Def Arc 100 Feet	Skew 25 Ft	
0	40.4	103.553	.005	159.046	27° 39.9′	34.75		0	[illegible]	101.761	[illegible]	158.069	28° 09.1′	35.05	
1		103.523		.030	40.4	34.76		1		101.731		.053	09.6	35.06	
2		103.493		.014	40.9	34.76		2		101.702		.036	10.1	35.06	
3		103.463		158.997	41.3	34.77		3		101.672		.020	10.6	35.07	
4		103.433		[illegible]	41.8	34.77		4		101.642		[illegible]	11.1	35.07	
5		103.402		.965	42.3	34.78		5		101.613		157.987	11.6	35.08	
6		103.372		.949	42.8	34.78		6		101.583		.971	12.1	35.08	
7		103.342		.933	43.3	34.79		7		101.554		.954	12.6	35.09	
8		103.312		.916	43.8	34.79		8		101.524		.938	13.1	35.09	
9		103.282		.900	44.3	34.80		9		101.495		.922	13.6	35.10	
10	40.5	103.252	.005	158.884	27° 44.7′	34.80		10	41.0	101.465	.005	157.905	28° 14.1′	35.10	
11		103.222		.868	45.2	34.81		11		101.436		.889	14.5	35.11	
12		103.192		.852	45.7	34.81		12		101.406		.872	15.0	35.11	
13		103.162		.835	46.2	34.82		13		101.377		.856	15.5	35.12	
14		103.132		.819	46.7	34.82		14		101.347		.839	16.0	35.12	
15		103.102		.803	47.2	34.83		15		101.318		.823	16.5	35.13	
16		103.072		.787	47.7	34.83		16		101.288		.807	17.0	35.13	
17		103.042		.771	48.1	34.84		17		[illegible]		[illegible]	17.5	35.14	
18		103.012		.754	48.6	34.84		18		101.229		.774	18.0	35.14	
19		102.982		.738	[illegible].1	34.85		19		101.200		.757	18.5	35.15	
20	40.6	102.952	.005	158.722	27° 49.6′	34.85		20	41.1	101.170	.005	157.741	28° 19.0′	35.15	
21		102.922		.706	50.1	34.86		21		101.141		.724	19.5	35.16	
22		102.892		.689	50.6	34.86		22		101.112		.708	20.0	35.16	
23		102.862		.673	51.0	34.87		23		101.082		.691	20.5	35.17	
24		102.832		.657	51.5	34.87		24		101.053		.675	21.0	35.17	
25		102.802		.641	52.0	34.88		25		101.023		.658	[illegible]	[illegible]	
26		102.772		.624	52.5	34.88		26		100.994		.642	22.0	35.18	
27		102.743		.608	53.0	34.89		27		100.965		.625	22.5	35.19	
28		102.713		.592	53.5	34.89		28		100.935		.609	22.9	35.19	
29		102.683		.576	54.0	34.90		29		100.906		.592	[illegible]	35.20	
30	40.7	102.653	.005	158.559	27° 54.5′	34.90		30	41.2	100.876	.005	157.576	28° 23.9′	35.20	
31		102.623		.543	54.9	34.91		31		100.847		.559	24.4	35.21	
32		102.593		.527	55.4	34.91		32		100.818		.543	24.9	35.21	
33		102.563		.510	55.9	34.92		33		100.788		.526	25.4	35.22	
34		102.533		.494	56.4	34.92		34		100.759		.510	25.9	35.22	
35		102.504		.478	56.9	34.93		35		100.730		[illegible]	26.4	[illegible]	
36		102.474		.461	57.4	34.93		36		100.701		.477	26.9	35.23	
37		[illegible]		.445	57.7	34.94		37		100.671		.460	27.4	[illegible]	
38		102.414		[illegible]	58.4	34.94		38		100.642		.444	27.9	35.24	
39		102.384		.413	58.8	34.95		39		100.613		.427	28.4	35.25	
40	40.7	102.355	.005	158.396	27° 59.3′	34.95		40	41.3	100.583	.005	157.411	28° 28.9′	35.25	
41		102.325		.380	59.8	34.96		41		100.554		.394	29.4	35.26	
42		102.295		.364	28° 00.3′	[illegible]		42		100.525		.378	29.9	35.26	
43		102.265		.347	00.8	34.97		43		100.496		.361	30.4	35.27	
44		102.236		.331	01.3	34.97		44		100.467		[illegible]	[illegible]	35.27	
45		102.206		.315	01.8	34.98		45		100.437		.328	31.4	35.28	
46		102.176		.298	02.3	34.98		46		100.408		.312	31.9	35.28	
47		102.146		.282	02.8	34.99		47		100.379		.295	32.4	35.29	
48		102.117		.266	03.2	34.99		48		100.350		.278	32.9	35.29	
49		102.087		.249	[illegible]	35.00		49		100.320		.262	33.4	35.30	
50	40.8	102.057	.005	158.233	28° 04.2′	35.00		50	41.3	100.291	.005	157.245	28° 33.9′	35.30	
51		102.028		.216	04.7	35.01		51		100.262		.229	34.4	35.31	
52		101.998		.200	05.2	35.01		52		100.233		.212	34.9	[illegible]	
53		101.968		.184	05.7	35.02		53		100.204		.196	35.4	[illegible]	
54		101.939		.167	06.2	35.02		54		100.175		.179	35.9	[illegible]	
55		101.909		[illegible]	06.7	35.03		55		100.146		.162	36.4	[illegible]	
56		101.879		[illegible]	07.2	35.03		56		100.116		.146	36.9	[illegible]	
57		[illegible]		.118	07.7	35.04		57		100.087		.129	37.4	[illegible]	
58		101.820		.102	08.2	35.04		58		100.058		.113	37.9	[illegible]	

17. Levels

Precise Leveling differs from ordinary leveling in the instruments emloyed and the care and refinement used in doing the work. Precise levels re generally run in establishing elevations for a long line of bench-marks. n the United States 13 000 bench-marks have been established by about l 000 miles of this class of leveling. See (4), (7), (10a), (24b) and (24c).

Instruments Used. The level may be either of the wye or dumpy type, e latter being used to a considerable extent in the work of the U. S. Coast d Geodetic Survey. The telescope is inverting and in some of the latest struments is made of a metal having a low coefficient of expansion. Prese levels are generally provided with three plate leveling screws and two nall plate levels besides the level tube under the telescope. Attached to e instrument is a mirror or a set of prisms so situated that the observer n see the long level bubble when reading the rod. At the eye end of e instrument, a micrometer screw is placed underneath the level bar y means of which the telescope and its attached level can be lowered or ised. The two plate levels are used to bring the instrument to an aproximate level and the micrometer screw is used to accurately center the ıbble under the telescope. Besides the central horizontal wire, the teleope is provided with stadia wires for the determination of the lengths of ghts. The tripod is constructed so as to give adequate stiffness in supportg the instrument. The rods are of the non-extensible type and of special oss-section, graduated to centimeters. Metal supports for the rod, which ay be driven into the ground for temporary turning points, rod levels, a ind shield, and a sun shade are also used in carrying on the work.

The U. S. Coast and Geodetic Survey in its precise level work makes two runs of ch line, one in a forward and the other in a backward direction. To obtain different mospheric conditions, the two runs are made at different times of day, cloudy days ving the best results. The instrument is always protected from the sun by a large nbrella. Two rods are used and at each station each rod is read, the same rod being ad first each time. The temperature of the rod is also recorded. The rods are refully standardized twice each year and corrected lengths due to changes in temrature computed. Backsights and foresights are made as nearly equal as possible d if any material difference occurs in these lengths corrections for curvature are plied. The forward and backward run of a section must agree in millimeters to thin $4\sqrt{\text{DISTANCE IN KILOMETERS}}$. This is equivalent to an agreement of about)16 ft per mile.

Bench-Marks. The U. S. Coast and Geodetic Survey and other governent departments have established elevations for bench-marks by precise ethods in many parts of the country. These elevations are usually rerred to the elevation of mean high water as a datum. If such bencharks are obtainable they may be used as a reference in extending lines bench-mark levels. Except in city work it is not essential to use precise ethods in extending the system of bench-marks as far as highway surveys e concerned. Ordinary methods of leveling, exercising due care, will ve sufficiently accurate results. Altho it is more convenient to have all rveys referenced to a line of bench-marks established from the same tum, many state highway surveys are made with the levels based on me assumed datum where benches referenced to a tide water datum nnot be found. A datum can be assumed from a good contour map or fact any datum can be assumed as long as it is of sufficient height so at no minus elevations will occur in the survey. Some states have made tensive surveys and established frequent bench-marks to be used in nnection with highway surveys. In other states the bench-mark eleva-

tions are established when the survey of the highway is made. Points for bench-marks should be of a stable and permanent character and their location should be clearly described so that they may be readily found at any time. Special markers are used for bench-marks established by the government surveys and some of the states. In connection with road surveys at least one permanent bench-mark should be established every 1000 ft along the line.

Profile Leveling consists in obtaining elevations of points along the transit line and the establishment of intermediate bench-marks. Elevations are taken at every 50 or 100-ft station and at other points between stations so as to give, when plotted, a true profile of the earth's surface along the transit line. Profile levels should also be run along the center line of every intersecting street, road or driveway for a distance of at least 200 to 300 ft from the transit line.

Cross-Section Leveling consists of taking levels along lines at right angles to the transit line for a width sufficient to cover the proposed improvement. These levels are taken at every 50 or 100-ft station and at points between stations where the slopes change. Enough points should be taken to define the surface. The elevations of car tracks, curbs, gutters, edges of traveled way, bottoms and tops of banks, together with their distances out from the transit line should be taken on each cross-section. Elevations should also be taken at the corners of houses, at the ground line and at the sill where there is any possibility of the improvement disturbing the property. Elevations of tops and bottoms of all culverts and drains at both ends should be determined. A line of levels should be run along the ditches to culverts at both the inlet and outlet ends. Where bridges occur, elevations should be taken of bridge seats, bridge floors, tops of parapet walls, high water marks, points that will define the stream bed at the bridge and points along the banks of the stream above and below the bridge. Elevations of manhole covers, gate boxes and ledge outcrops should also be taken.

Running the Levels. Profile and cross-section levels are usually taken by the same field party that runs the transit line after the latter has been laid out. It may be advisable, however, under certain conditions to have these levels run by a separate party. Sometimes the profile and cross-section levels are taken at the same time, while some prefer to complete the profile levels before the cross-section levels are taken.

The levels may be taken either with a transit or a level. The transit, if in adjustment and carefully used, is sufficiently accurate for the work. Some type of self-reading rod, graduated to feet and hundredths of a foot, is employed. Self-computing rods with which the elevation of a point can be read from the rod are very convenient for parts of the work. As the levels are run after the transit line is staked out, the only measurements necessary are those to plus stations and to points to be located in the cross-section levels. These measurements may be made with a metallic tape.

The instrument is set up and leveled near a point the elevation of which is known. The rod is held vertically on this point and a sight is taken on the rod thus obtaining the rod reading which is the intersection of the middle horizontal cross-hair with the rod. This is called a backsight or B. S., and when added to the elevation of the point on which the rod was held gives the height of the instrument or H. I. The rod is now held on points whose elevations are to be determined and the rod readings obtained, called foresights or F. S., are subtracted from the H. I., thus giving the elevations of the points. The elevations of as many points as possible are determined with this set-up of the instrument and a foresight is taken on some well defined and solid point called a turning point or T. P. The

instrument may now be moved to another set-up and a new H. I. obtained by taking a B. S. on the T. P. The elevations of other points may now be determined as before. Bench-marks or B. M.'s should be established as the work progresses. All backsights are plus sights and all foresights are minus sights. No sights should be taken over 300 ft in length. The rod should be read to the nearest hundredth of a foot on turning points and bench-marks, and to the nearest tenth of a foot on most of the other points. Care should be taken to equalize the backsights and foresights to turning points. The chief of party takes notes, one man runs the instrument, another holds the rod and the zero end of the tape, while the third man holds the other end of the tape and calls off the distances from the transit line to the points at which the rod is held.

If the self-computing rod is used the instrument is set up and the rod held on the bench-mark or B. M. The graduated ribbon belt on the rod is pulled up or down until the line of sight coincides with a graduation the same in feet and hundredths as the elevation of the bench. The ribbon is clamped in this position. The elevation of other points where the rod is held is given by the rod reading itself. The elevation of a T. P. is found in this way, the instrument moved to a new set-up, the graduated ribbon reset to correspond to the elevation of the T. P. and work continued.

B. S.	H. I.	F. S.	Elev.	
			50.00	B. M. Bolt in boulder east side Sta. 531 ±
3.19	53.19			
		5.5	47.69	Sta. 600 C
		5.9	47.29	7.5 L
		6.1	47.09	12.0 L T. W.
		7.2	45.99	13.0 L
		6.2	46.99	15.0 L
		5.8	47.39	11.5 R T. W.
		6.3	46.89	17.0 R rail
		6.5	46.69	Sta. 650 C.
		7.1	46.09	8.0 L
		7.3	45.89	12.5 L T. W.
		8.1	45.09	14.0 L
		6.8	46.39	16.5 L
		6.7	46.49	10.0 R T. W.
		7.2	45.99	16.0 R rail
		12.34	40.85	T. P. Sta 619 nail in oak east side.
5.57	46.42			
		4.8	41.62	Sta. 700 C
		5.2	41.22	9.5 L
		5.9	40.52	12.0 L T. W.
		6.9	39.52	14.0 L
		5.4	41.02	17.0 L
		5.1	41.32	11.0 R T. W.
		5.4	41.02	20.0 R
		7.3	39.12	Sta. 750 C
		7.5	38.92	10.0 L
		8.3	38.12	11.0 L T. W.
		9.4	37.02	15.0 L

Fig. 31. Level Notes

Example. Suppose the elevation of initial B. M. was 554.75. The rod is held on B. M. and the ribbon set so that the line of sight coincides with 4.75. Hold the rod on the point whose elevation is desired, read the rod and prefix the number 55 to the rod reading. This will be the elevation of the point.

Methods of recording the field notes are shown in Figs. 31, 32, and 33. Instead of figuring the elevation of each point as shown in Figs. 32 and 33, sometimes the elevation of the point on the cross-sections with reference to the height of instrument is plotted, using the rod readings corresponding to the point in question. The rod readings are always scaled downward from the datum on the cross-sections corresponding to the height of instrument.

When the profile and cross-section levels are taken simultaneously, it is necessary to figure the elevation of each point from the field notes so that these elevations can be plotted. Some engineers prefer to run a line of

profile levels on the transit line with the instrument and then work up the cross-section levels by means of a hand level. In this case the cross-section levels can be plotted from the rod readings which give the distances of the points above or below the calculated elevations of the center line profile.

Contour Levels. Topographical surveys consist in part in taking levels from which contour maps can be prepared. Profiles and cross-sections may be read off from a contour map and fairly accurate results for heavy grading obtained if the contour interval is small. The method of contours for showing a configuration of the earth's surface is more adaptable, however, to extensive areas than it is to surveys for highways. Contour levels are frequently taken in connection with railroad surveys but the method of cross-section levels is more usually employed in highway surveys.

Sta.	B. S.		H. I.		F. S.	Elev.	
B.M. No. 1	Spike in root of elm tree east of Sta. 0+20					100.00	
	5.62		105.62				
	Left			Transit Line		Right	
0	28	17	9	0	11	19	36
	9.5	11.5	10.5	9.3	10.1	11.5	12.4
	96.12	94.12	95.12	96.32	95.52	94.12	93.22
1	27	13	5	0	13	20	27
	7.9	7.3	5.9	5.6	6.3	7.1	6.9
	97.72	98.32	99.72	100.02	99.32	98.52	98.72
2	25	16	7	0	9	15	30
	6.3	5.6	3.6	3.1	3.9	4.3	4.6
	99.32	100.02	102.02	102.52	101.72	101.32	101.02
T.P. 2+25					4.33	101.29	
	4.85		106.14				
3	23	19	10	0	10	20	35
	12.4	11.9	11.3	10.1	10.7	10.8	12.1
	93.74	94.24	94.84	96.04	95.44	95.34	94.04
4	25	20	9	0	11	18	30
	11.0	10.0	9.2	8.2	8.7	8.5	10.0
	95.14	96.14	96.94	97.94	97.44	97.64	96.14
T.P. 4+75					2.57	103.57	
	10.20		113.77				
5	27	21	11	0	12	19	27
	11.7	11.5	10.7	10.1	10.8	10.0	11.8
	102.07	102.27	103.07	103.67	102.97	103.77	101.97

Fig. 32. Level Notes

A Contour Line is the line of intersection of a horizontal plane of known elevation with the earth's surface. Every point on this line, therefore, has the same elevation. Contour maps are prepared showing contour lines at definite intervals apart, usually some multiple of a foot. Thus for a 1-ft interval, the contour lines would represent points differing in elevation by 1 ft, for a 10-ft interval the points of two adjacent contours would be 10 ft different in elevation. The slope of the ground between any two contour lines is considered uniform.

Contour levels may be taken by any one of the following methods:

With the Stadia elevations of points and their location are obtained. The points selected are those defining changes of slope, summits, depressions, ridges and valleys. The locations and elevations of these points are plotted and contour lines can then be drawn by interpolating the contours between the elevations of the known points.

With the Plane-Table the method is the same as with the stadia except that the contours are often drawn in the field and a more accurate map thus obtained.

The Level or Hand Level is used for contour work, generally only in surveys of small width but great length, such as a highway survey. In this case the different contours are actually located in the field thruout the area of the right-of-way. The profile

leveling is usually done in advance of the contour work. Points on the contour lines are taken on lines at right angles to the center line at each regular station interval and at as many intermediate stations as are necessary to fully trace out the contours. The principle of the work is as follows: Knowing the H. I., a level or hand level being used, the rod reading to obtain a point on a contour may be found by subtracting the contour elevation from the H. I. The rodman walks along a line at right angles to the center line until the instrumentman obtains this rod reading, the point on the ground then corresponds to a point on the contour of that elevation. The distance from the center line to the point is measured. By adding or subtracting the contour interval

Fig. 33. Level Notes

to or from the previous rod reading depending upon whether the ground is falling or rising, and continuing along the same line, a point on another contour line will be found. This same method is continued until all points have been located at that station or set-up and then the same operations are carried out at the next station. Having the points located on the contours at each station, the contour lines between the stations can be traced out by inspection and sketched in the field book.

Check Levels. The level work is commonly checked by running levels backward over the line to the starting point, holding the rod only on the T. P.'s and B. M.'s established in the forward run. A closed circuit is thus formed. The elevation of the starting point calculated from the levels should agree with its original elevation within the limit of error fixed

for the work. If B. M.'s have been previously established by an independent survey, a check on the new level work can be obtained by tying in the new levels with these B. M.'s as the work progresses and noting if the difference in elevation is within the allowable limit. Another method of checking the work as it progresses is that known as double rodding the line. In this method two T. P.'s are always chosen, differing in elevation by at least 1 ft. A foresight is taken on each T. P., and two corresponding backsights when the instrument is moved. The two H. I.'s are calculated and their agreement noted. Precise leveling requires an accuracy of about 0.016 ft per mile. For highway work an accuracy of 0.1 ft per mile is allowable. If a long line of benches is being run, however, it would be advisable to make the accuracy approach nearer that required by precise leveling. In the method of double rodding the line, the two H. I.'s should agree within about 0.012 ft to keep within an accuracy of 0.1 ft per mile.

18. Staking Highway Surveys

There are several methods of staking surveys so that construction work can be performed from information obtained from the stakes. The essential information required is alignment and grade. Stakes may conveniently be prepared by sawing a 2 by 3 in rectangular piece of wood 24 to 30 in long in two on the long diagonal, thus giving two wedge shaped stakes to each piece.

Road Surveys. One method is to drive stakes at the time the survey is made. One or two lines of stakes are driven at the side of the road far enough away so as not to be disturbed. Two lines are preferable in which case a line is driven on each side of the road. The stakes are driven at each station interval on the tangent, either 50 or 100 ft apart, and on curves may be spaced closer, depending upon the length and the degree of curve. Sometimes the stakes are driven on a definite offset from the center line, but it is better to let the offsets vary in amount, and place the stakes at convenient points. Ground elevations, elevations of tops of stakes and offsets from the stakes to the transit line are measured in the field. The station numbers and offsets are marked on the back and side of each stake. A sheet is prepared in the office on which is given the elevations of tops of stakes, offsets of stakes from the transit line at each station, elevations of finished center line grade at each station, and offsets from transit line to the finished center line of road. With this sheet in hand, the stakes are marked in the field with the correct offset to the finished center line. Marks are put on the faces of the stakes towards the road to define the grade.

Another method is to set stakes just before construction work is started. In this case marks defining the center line grade are placed on the stakes by running grade levels. Offsets to the stakes from the finished center line are measured after the stakes are driven and marked on the stakes. Fig. 34 shows a form of grade level notes. The foresights to obtain the center line grade are found by subtracting the center line grade elevations given in the column headed Elevations from the H. I. The columns marked Right and Left are for rod readings on two lines of stakes, one on the right and the other on the left side of the road. The rod is held on a stake and moved up or down until the rod reading under F. S. is obtained or a reading varying from this by some multiple of a foot, and then a notch is cut in the edge of the stake at the bottom of the rod. The station number

is marked on one side or on the back of the stake, the offset to the center line on the side and the grade on the face of the stake towards the road. If a grade mark is the same elevation as the center line grade, the stake is marked Gr. If the mark is placed so as to be some multiple of a foot above or below the center line grade the stake is marked 2′ ↓, for example, which would mean that the finished grade was 2 ft below the mark. If stakes come in driveways or intersecting roads where they would be disturbed, they should be driven flush and the grade referenced with the top. The same grade mark that is placed on the stake is entered in the book.

Sta.	B. S.	H. I.	F. S.	Grade Elev.	Stakes Right	Stakes Left
B.M.	Bolt in side St	boulder a. 531 ±	east			
				50.00		
	4.53	54.53				
5			7.28	47.25	6.28 $1'\downarrow$	7.28 Gr.
5+50			7.68	46.85	9.68 $2'\uparrow$	8.68 $1'\uparrow$
6			8.08	46.45	8.08 Gr.	9.08 $1'\uparrow$
6+50			8.48	46.05	9.48 $1'\uparrow$	7.48 $1'\downarrow$
T.P.			10.21	44.32		
	3.17	47.49				
7			2.44	45.05	3.44 $1'\uparrow$	8.44 $1'\uparrow$
7+50			3.44	44.05	3.44 Gr.	5.44 $2'\uparrow$
8			4.44	43.05	6.44 $2'\uparrow$	2.44 $2'\downarrow$

Fig. 34. Grade Stake Notes

With stakes set and marked by either of these two methods, the elevation and alignment of the finished road center are established. Knowing the width and shape of the cross-section of the road, as many stakes as desired can be set at different points in the cross-section by referencing them in with the line and grade of the center line.

Where a car track occurs in a road, staking other than for stationing is frequently unnecessary since the center line grade may be referenced with regard to the rails of the track as so much above or below the rails, a definite distance out to the center of road from the rail being given for the alignment of the center line.

Many states make a practice of permanently monumenting the road surveys. Stone bounds, one on each side of the road, on the property lines, are set at each P. C. and P. T. where a curve is used or, if a curve is not required, on a line thru the point of intersection bisecting the interior angle between the tangents.

Another method of staking surveys is to drive three stakes at each station, one in the center and a slope stake at either side at the toe of the finished slope. The cuts or fills to grade are marked on each stake. The station number is also marked on the stake at the center and the distance out from the center is marked on each slope stake.

Setting Slope Stakes. Slope stakes are not essential except in cases of heavy grading or unless the last method mentioned for staking the road is used. Slope stakes may be set with a level or with a hand level. The stakes are set by a cut and try method at the points where the side slopes intersect the ground surface. In Fig. 35 a b is the original ground line; h h_1 h_2, the vertical distances from the finished grade of road bed f g to the ground line; s the cotangent of the angle of slope a; W the width of road bed; x_1, x_2 the distances as shown; and d_1, d_2 the horizontal distances from the center to the stakes a and b respectively. If a b is level; $h = h_1 = h_2$; $x_1 = x_2 = s\,h$; $d_1 = d_2 = W/2 + s\,h$. The points a and b are thus readily found. If the ground is not level, the heights h_1 and h_2 will not be equal to h. In this case the points a and b would be found by trial. To locate a, for instance, a ground elevation on the cross-section line would be taken

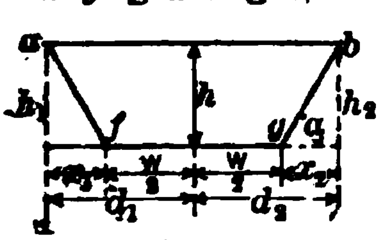

Fig. 35

and the distance out to the point where the rod was held would be measured. Knowing the distance of this point above the level of the road-bed, in case of a cut, its distance out from the center is calculated. If this distance agrees with the measured distance to the point where the rod was held, *a* would be the point at which slope intersected the ground. If an agreement is not reached between the calculated and measured distance on the first trial, other points are tried until the two distances do agree. If the slope of the ground is estimated by eye, the point to set the slope stake can be found by two or three trials. The form of field notes for this method is shown in Fig. 36. Slope stakes may also be set by laying off distances from the center line to the bottoms or tops of slopes which have been scaled from the plotted cross-sections.

Sta.	Center Line Ground	Center Line Grade	Left	Stakes Center	Right
5	95.6	90.0	+6.0 / 19.0	+5.6 / 0.0	+10.0 / 25.0
5+30	89.5	88.8	0.0 / 10.0	+0.7 / 0.0	+0.5 / 10.7
5+40	88.4	88.4	−0.4 / 10.6	0.0 / 0.0	+0.4 / 10.6
5+60	86.8	Fall 4% 87.6	−1.0 / 11.5	−0.8 / 0.0	0.0 / 10.0
6	84.0	86.0	−7.0 / 20.5	−2.0 / 0.0	−5.0 / 17.5
7	77.5	82.0	−8.6 / 22.9	−4.5 / 0.0	−8.0 / 22.0
8	72.0	78.0	−10.0 / 25.0	−6.0 / 0.0	−6.4 / 19.6
9	71.0	74.0	−4.8 / 17.2	−3.0 / 0.0	−5.4 / 18.1

Fig. 36. Slope Stake Notes

Street Surveys. Stakes for rough grading are set by any of the methods described under road surveys. Curbs are usually placed before the improvement of the pavement of the roadway is undertaken. On narrow roadways, elevations for the construction of the pavement may be obtained from lines on the curbs without setting any stakes. Templates conforming to the shape of the crown may be used to advantage. On wide roadways it is better practice to set lines of stakes defining the grade of the finished cross-section along the roadway at intervals of 50 ft. The number of stakes required to define the cross-sectional grade will depend upon the width of street and the shape of the crown. The monumenting of street surveys has been described in Art. 6.

Staking Curbs. One method is to drive a line of stakes on an offset defining the line of the curb, making the tops of the stakes conform to the grade of the curb. Another method preferred by many engineers is to use a line of offset stakes as in the previous method but to drive them flush with the ground. Elevations are taken on the tops of the stakes and a sheet prepared showing the elevation of the curb with reference to the stakes.

A convenient way to mark with a transit the grades on the stakes in the first method outlined above, where the grade is a uniform rate for a number of stations, is as follows: Set up the instrument near the first station and mark the grade. Set up the instrument near the last station of the uniform grade and mark the grade on that stake. Set the transit over the stake and measure the distance from the horizontal axis to the grade mark. Clamp the target on the rod at this distance. Carry the rod to the first station

and hold on the grade mark. Elevate or depress the telescope until the horizontal cross-hair bisects the target and then clamp the horizontal axis. The rod is then held on the intermediate stakes and raised or lowered until the line of sight bisects the target. The bottom of the rod will then be grade.

If the transit has a gradienter screw, the telescope may be elevated or depressed by turning the screw so as to be parallel to any rate of grade. The H. I. above the grade mark at the initial station is found, when the transit is set over the stake, by measuring the distance to the horizontal axis from the grade mark. The target on the rod is clamped at this distance. The telescope is made parallel to the rate of grade by the gradienter screw. Grade elevations for other stakes on the line where the grade is uniform are found by holding the rod on them and moving it up or down until the target is bisected as described in the previous paragraph.

Staking Borrow-Pits. Places outside of the right-of-way location from which excavated material to be used in the road construction is taken are called borrow-pits. In order to estimate the quantity of excavation taken from a pit, the pit must be cross-sectioned. The following method is usually the most convenient one to use: The area to be excavated is divided into 10 or 20-ft squares by lines of stakes at right angles to each other set by means of a transit and tape. A stake is placed at every corner of each square and appropriately marked (see Fig. 37). Levels of the ground at each stake and at intermediate points, if the slope between stakes is not uniform, are obtained. If the edge of a bank comes between stakes, the plus distances are noted and levels are also taken at these points (see irregular line in the figure). It is best to make a sketch of the pit in addition to obtaining the level notes, and to place the elevations of each point on the sketch. When excavation in the pit has been finished, the same squares as in the beginning are again laid out and levels again taken at each corner. Care should be taken in first staking out the pit to provide reference points on one or more lines far enough away from the work so as not to be disturbed. Such points are of great help in restaking the pit.

Fig. 37

The Volume of Borrow-Pits may be found by adding together the computed volumes of the rectangular and triangular prisms and pyramids into which the solid is divided. The area of the bases of these solids can be found from the sketch and their altitudes from the levels. Referring to Fig. 37, the volume of the solid $d_1\, d_2\, c_2\, c_1$ is equal to $A(h_1 + h_2 + h_3 + h_4)/4$, where A is the area of the base, in this case 400, and h_1, h_2, h_3, h_4, the heights of the four sides obtained from the difference of the initial and final levels at the corners. In the square $d_3\, c_3\, d\, c$ the solid is made up of a rectangular prism with a base $d_3\, m\, n\, c_3$ and a triangular prism with a base $m\, n\, o$. The volume would be the sum of these two volumes. The area of the base of the rectangular prism and the heights at m and n would be calculated from the levels and its volume found from the formula given above. The volume of the triangular prism would be $A\,(h_1 + h_2 + h_3)/3$, where A is the area $m\, n\, o$, and h_1, h_2, h_3, the side heights at m, n and o. The volume of a solid like $c_2\, c_3\, d_3\, d_2$, where an intermediate point p has been taken in the center of the square, would be the sum of the rectangular prism and a pyramid if p was higher than the points at the corners or the difference of the two volumes if p was lower. The volume of the rectangular prism would be found as previously shown. The volume of the pyramid would be $A \times$

ALTITUDE / 3, where A is the area of the base, in this case 400 sq ft. If h_p equals the difference in initial and final elevations on point p and h_1, h_2, h_3, h_4, the heights of the sides on the four corners of the square, the altitude of the pyramid is equal to $h_p - (h_1 + h_2 + h_3 + h_4)/4$. If an intermediate point s is taken on the middle of the side of a square as in $d_1\, d_2\, c_2\, c_1$, the volume is the sum of the rectangular prism and a pyramid. The altitude of the pyramid in this case would be the height $h_s - \frac{1}{2}(h_1 + h_2)$, where h_1 and h_2 are the heights at c_1 and c_2 respectively. Where intermediate points occur other than in the center of the square or in the center of the side, the volume would be found by dividing the solid into four triangular prisms as indicated by the broken lines in square $c_1\, c_2\, b_2\, b_1$. See (1), (4), and (14).

19. Final Highway Surveys

It is advisable in highway work to make a final survey after construction work has been finished. A final survey will show how the work as constructed conforms to the original plan. Plans are frequently changed in the field and a final survey records all such changes. A final survey is also of value in settling claims for damages to abutting property. The final estimate is usually computed from the final survey.

A final survey is made in the same manner as the original survey and all of the information is referenced to the original transit line. The center line of the finished roadway, its width, and location of all improvements and monuments are obtained. Cross-sections at each station are taken as in the original survey. The information obtained in the final survey is plotted on the original plan and cross-sections.

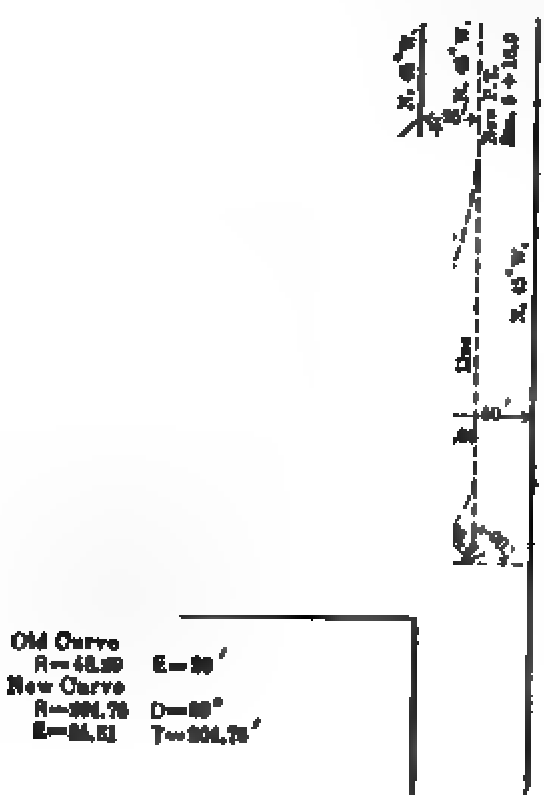

Fig. 38

20. Right-of-Way Surveys

It is frequently necessary to take parcels of land abutting the highway where curves are flattened, detours are made, or increased width of right-of-way is desired. The survey of the land is made with reference to the transit line of the highway survey by means of a closed traverse and the area enclosed calculated. A deed of the parcel taken is made out and recorded. A very simple but common case is illustrated in Fig. 38. The old road has a very sharp turn at the intersection. To obtain a good sight distance and an easy curve around the corner, it is necessary to take a corner of John Jones' property. Data for the old and new curve are shown in the figure.

A description of the piece which should be incorporated in the deed

would be as follows: Beginning at a point in the northerly boundary of the highway, 25.0 ft westerly, measured at right angles from Sta. 1 + 95.2 of the highway survey ....; thence N 45° E a distance of 179.8 ft along the northerly boundary of the highway to a point 49.5 ft measured westerly on a radial line from Sta. 3 + 56.06 of the highway survey; thence N 45° W a distance of 179.8 ft along the westerly boundary of the highway to a point 25 ft westerly measured at right angles from Sta. 5 + 16.9 of the highway survey; thence S 0° a distance 254.2 ft to the point of beginning; being an area of 0.371 acres more or less.

The area may be obtained by planimeter or by dividing the plot of the survey into simple geometrical figures, scaling the necessary dimensions, computing the areas of the separate figures and adding them together. The area may also be found by the method of double meridian distances.

Area by Double Meridian Distances. The latitude of a course equals the distance of the course times the cosine of the bearing; the departure of a course equals the distance of the course times the sine of the bearing. See (4) and (14). The latitudes and departures are computed with reference to two coördinate axes at right angles to each other, the latitudes being parallel to the vertical axis and the departures parallel to the horizontal axis. The vertical axis is drawn thru the most westerly point of the traverse. North latitudes and east departures are considered positive, south latitudes and west departures negative. The error of closure is first computed. If the field closes, the algebraic sum of the latitudes will be zero, and the algebraic sum of the departures will be zero. If there is an error of closure, and it is of an amount that could be expected without a serious error having been made, it is distributed over the various latitudes and departures according to the rule given in Art. 6. The algebraic sum of the corrected latitudes and departures will then be zero. The double meridian distance, D. M. D., of the first course equals the departure of the course. The D. M. D. of any other course equals the D. M. D. of the preceding course, plus the departure of the preceding course plus the departure of the course itself. Double areas are found by multiplying each D. M. D. of a course by its latitude. The sum of the double areas divided by two gives the area of the field. The area of the parcel in Fig. 38 is calculated by this method and tabulated as follows:

Bearings	Distance Ft	Latitudes	Departures	D.M.D.	Double Areas
N 45° E..........	179.8	+127.1	+127.1	127.1	16154.41
N 45° W..........	179.8	+127.1	−127.1	127.1	16154.41
S 0°.............	254.2	−254.2	0.0	0.0	0.0
Sum............		0.0	0.0		32308.82

Error of Closure
Latitude 0
Departure 0

$$\text{Area} = \frac{32308.82}{2} = 16154.41 \text{ sq ft}$$
$$= 0.371 \text{ acres}$$

HIGHWAY MAPS

21. Mapping the Plan

Road Surveys. The survey plan may be plotted on a sheet of detail paper having a width and a length suitable to take from ½ to 1 mile of survey. The plan should show the transit line, property lines, names of property owners, and all the topographical detail except the cross-sections of the road at the different stations. If elevations were taken for contour

lines, however, the contour lines would be drawn on the plan. The plan should have an appropriate title in which should be stated the scale of the plan. The field notes of the transit line should first be studied for the purpose of seeing in what position the line may be laid out on the sheet in order to have it come within the limits of the paper with as few breaks in the continuous plotting of the line as possible. An easy and quick way to do this is to calculate the lengths of tangents and then roughly plot the line to a small scale, say 1000 ft to the inch, on a piece of paper. Then, by using each one of the tangents as a base, scale the perpendicular heights from this line to the highest and lowest points of intersection. Some tangent will be found which, if plotted parallel to the long edge of the plan sheet, will enable one to plot the line with the least number of breaks. Several methods of plotting the transit line will be described.

The Coördinate Method. Having found the tangent which is to be placed parallel to the bottom of the sheet, the rectangular coördinates to the different intersection points are computed with reference to this line as a base. In Fig. 39, for instance, the coördinate $j\,k = j\,l \cos \alpha$ and the coördinate $l\,k = j\,l \sin \alpha$. Other coördinates are found in a similar manner. The coördinates with reference to the base line are then found by addition. The paper may be ruled off into large squares for convenience in plotting the calculated positions of the points. Accurate plotting may be obtained by prolonging the base line tangent $i\,j$ and plotting the other points from perpendiculars erected from this line, as $e\,f$ in Fig. 39, or by plotting the coördinates of each tangent with the last point of intersection as the origin as $l\,m$, $m\,n$ in the figure.

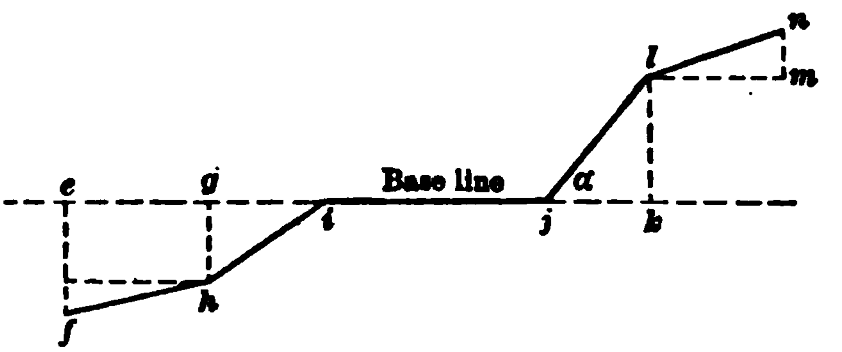

Fig. 39

The tangent $i\,j$ is plotted on the sheet in its proper position; the coördinates of the points are plotted from it as described above and the tangent lines $j\,l$, $l\,n$, etc, drawn between the points. The plotting should be carefully done and the scaled length of each tangent should be compared with the length given in the survey as a check. It is also advisable to check the angle between the tangents with a protractor.

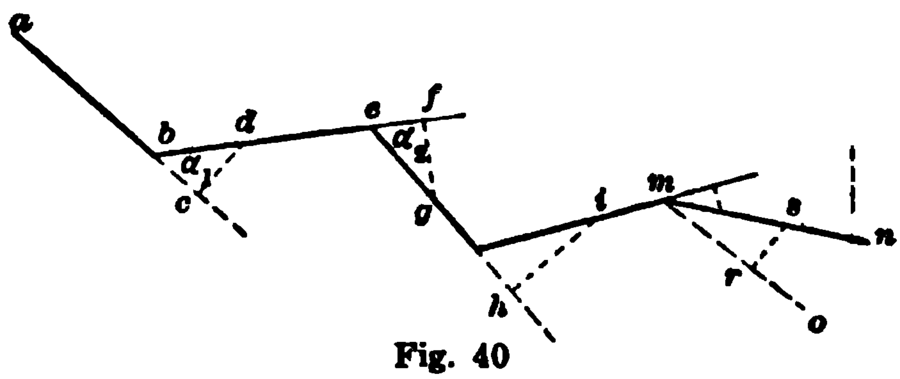

Fig. 40

The Tangent Method, shown in Fig. 40, consists of prolonging each tangent a definite amount $b\,c$, $e\,f$ and finding the tangential offsets $d\,c$, $f\,g$, etc. For instance, suppose the tangent was prolonged each time beyond the intersection 200 ft. Then $d\,c = 200 \tan \alpha_1$, $f\,g = 200 \tan \alpha_2$, etc. The line drawn from b thru d will give the direction of the tangent and its length will have to be scaled off in order to get the point of intersection e. This method is checked by calculating the bearings of all the tangents with respect to the first tangent $a\,b$ as a meridian. Draw thru the last intersection point a line $m\,o$ parallel to $a\,b$, scale the distance $r\,s$ and $m\,r$ and calculate the angle $s\,m\,r$ and compare it with the calculated bearing of $m\,n$ with respect to $m\,o$.

Fig. 41

Protractor Method. A very common method is to plot the line by means of a protractor and scale. Even with protractors graduated to read as small as 1′ of arc it is impossible to plot the line as accurately as by either of the two methods previously described. In some cases where a protractor is used, the transit line is

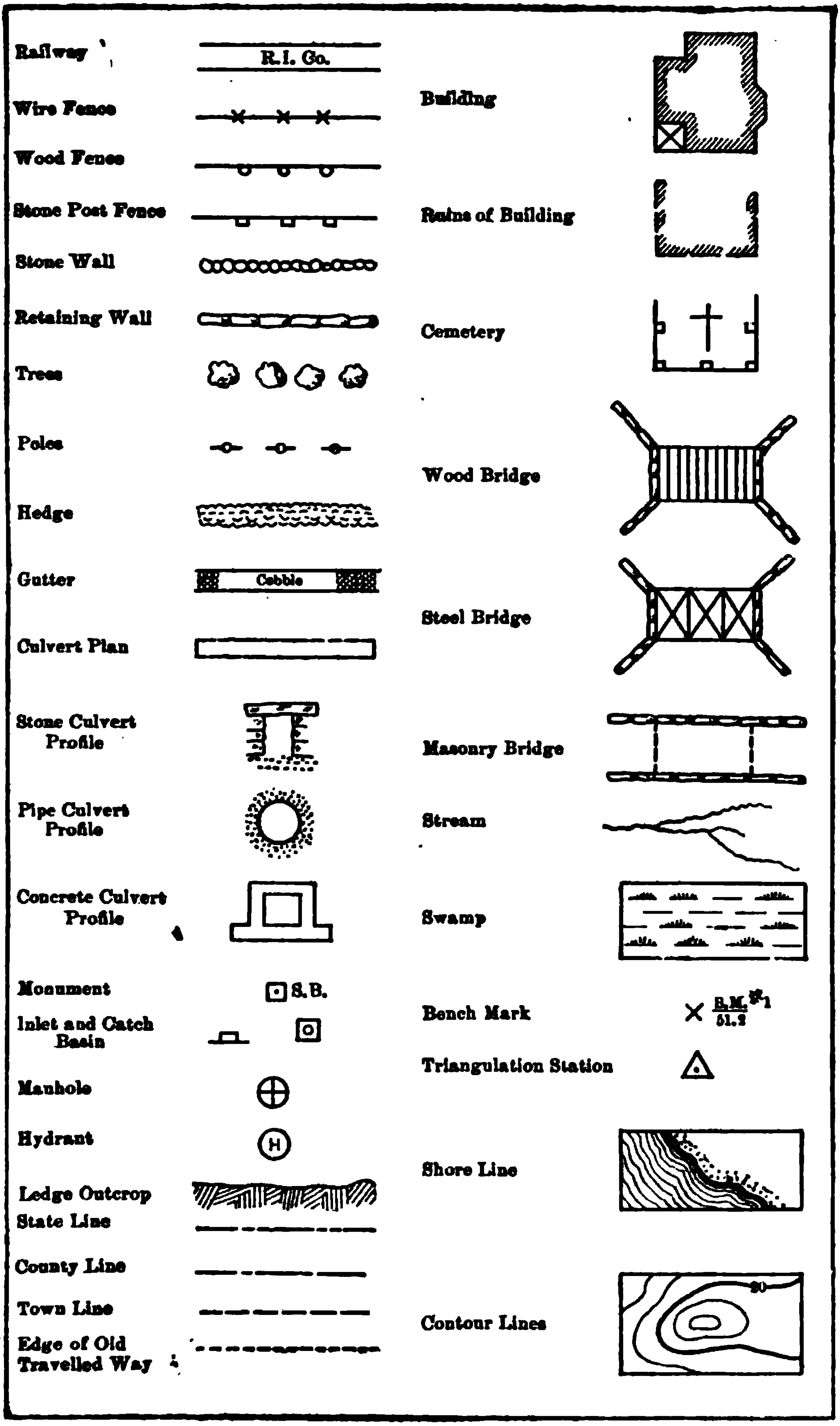

Fig. 42. Topographical Signs

broken at each intersection and plotted parallel to the long edge of the paper. A small length, say 200 ft, is plotted beyond each intersection as shown in Fig. 41. This method is used in preparing plans in some of the western states where the roads follow the section lines of the U. S. Land Survey and hence have but very few sharp angles.

The Curves are drawn in at the intersections when the plotting of the tangents has been finished. The stations are then scaled off and marked on the plan, using the same interval as was used in making the survey. This completes the plotting of the transit line.

The Topographical Details taken in the survey are now plotted with reference to the plotted transit line. Some of the topographical signs used are shown in Fig. 42.

Street Surveys. Plans of individual streets are plotted in a similar manner to those of road surveys.

Drawing Paper. Detail paper for mapping surveys can be obtained in sheets or rolls of various sizes. The paper is made in different grades.

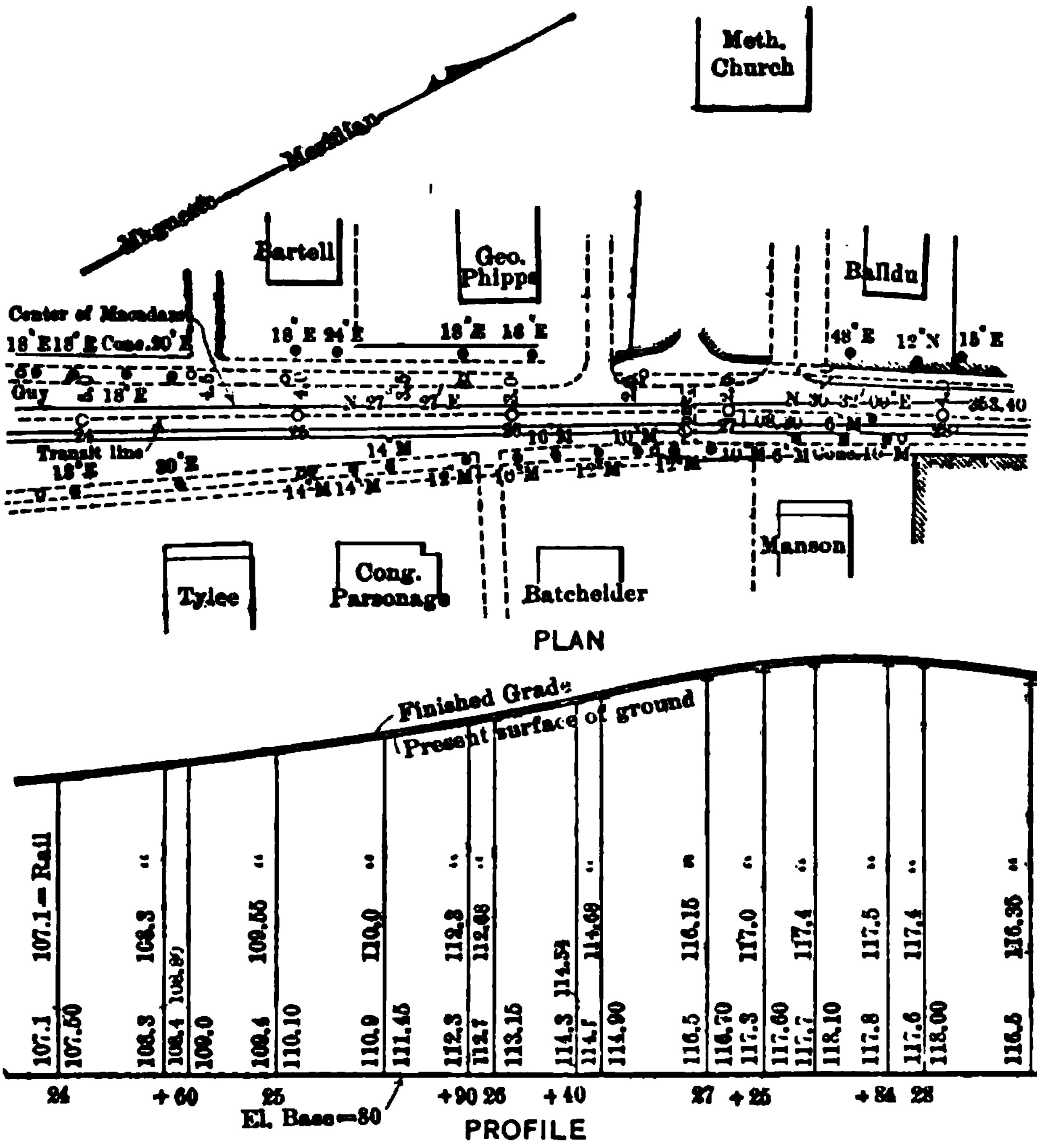

Fig. 43

It is advisable to use a grade of paper that is fairly heavy, will take ink and pencil well, that erasures can be made on without destroying the surface, and of a texture and color that will stand rough handling and not be easily susceptible to shrinking or stretching. Rolls may be obtained in various widths, from 24 up to 72 in and in lengths from 10 up to 100 yds.

Horizontal Scale. The horizontal scale used in plotting the plan is

generally either 40, 50 or 100 ft to the inch. The large scale is more convenient from the standpoint of studying the plan, but the small scale is preferred by some because of the consequent reduction in the size of the plan.

Tracings are made from the plan when it is completed so that blue-prints may be prepared. The tracings are inked on linen tracing cloth usually on

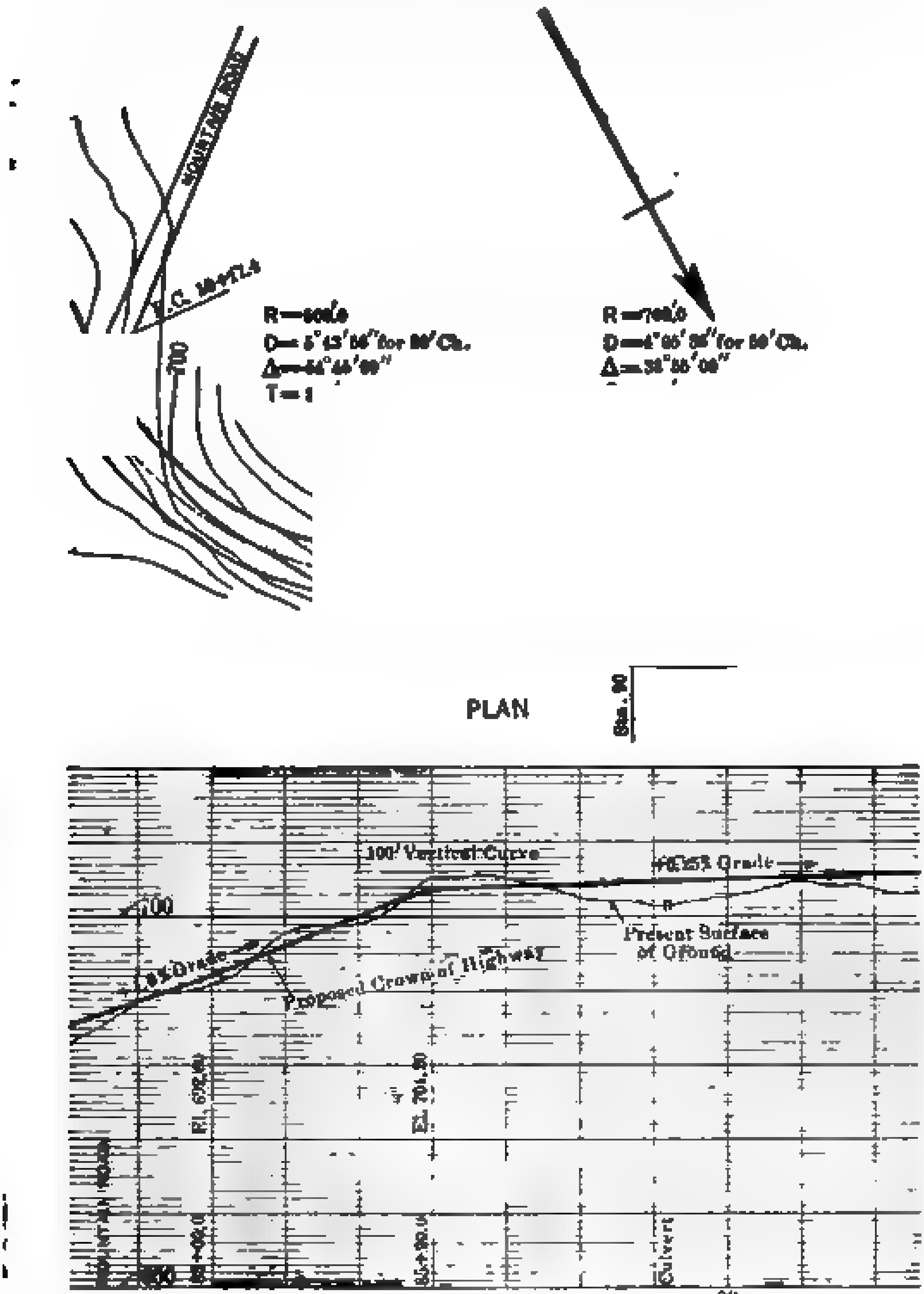

Fig. 44

the dull side. The tracing may be made the same size as the plan sheet but it is better to trace the plans on sheets of a standard and uniform size, say 24 by 36 in. These sheets are then bound together and are much more convenient to use in the field than a long continuous roll.

Portions of two completed plans and profiles are shown in Figs. 43 and 44, one of which shows the plan with contour lines.

22. Mapping the Profile

The Profile should show the elevations of the ground along the proposed center line. If the transit line is the proposed center line, the elevations for plotting the profile can be obtained from the notes. If the proposed center line departs from the transit line, profile elevations may be read off from the plotted cross-sections. The elevations of car tracks, bridge openings, manholes, culverts, corner boards of houses, curbs and ditch lines are also sometimes plotted on the profile. This information, when plotted on the profile, is of great help in establishing the finished center line grade, which is also drawn on the profile.

The profile may be drawn on the same sheet as the plan, in which case it is placed generally at the bottom of the sheet below the plan so that the stations of the plan will be approximately above the corresponding stations of the profile. A long base line is drawn called a datum line and an elevation given it sufficiently low so that the profile line will not come below it at any point. This line is stationed to correspond with the stations of the survey where center line elevations have been taken. The same horizontal scale is employed that was used in plotting the plan. Perpendiculars to the base line are erected at these points and the elevations of the points scaled off with reference to the elevation of the datum line. The points thus established are joined together by a line and the elevations and stations of the points are written along the perpendicular lines, the stations usually below the datum line and the elevations directly above (see Fig. 45). The other information mentioned, with the exception of the finished center line grade, is plotted in a similar manner. It is advisable to ink in the different lines of the profile after the plotting has been checked since frequent erasures are necessary in establishing the grade line. The different lines of the profile can be readily distinguished from each other by using different colored inks or by using broken or dot and dash lines to designate them. To lessen the work of drawing perpendiculars to the datum line in case of a profile having a great difference in elevation of the high and low points, the datum line is broken as shown in Fig. 46. Profiles may also be plotted on standard profile paper or cloth. The plotting in this case is much simplified as no scaling has to be done and no vertical lines have to be drawn.

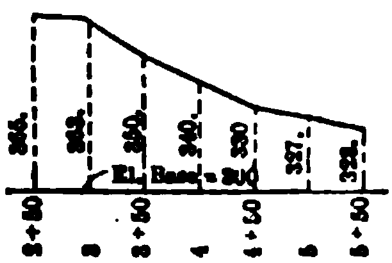

Fig. 45

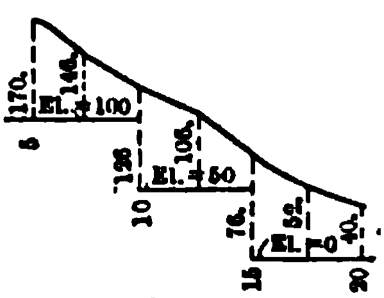

Fig. 46

Profile Paper and Cloth are manufactured in 20 and 50-yd rolls of drawing paper unmounted and mounted, tracing paper and tracing cloth. The rolls are ruled off (see Fig. 47) with vertical and horizontal lines in three styles or scales called Plates A, B and C. In Plate A there are 4 vertical spaces and 20 horizontal spaces to the inch. Plate B has 4 vertical and 30 horizontal and

Plate C, 5 vertical and 25 horizontal spaces to the inch. Rolls may be obtained with either red, orange or green lines and having engraved widths of 9, 10 or 20 in. Profile-plan paper or cloth may be obtained in continuous rolls which is very convenient for plotting of road surveys. In this style of paper the profile ruling with its margin is only half the width of the paper, the other half being left blank for the plan drawing.

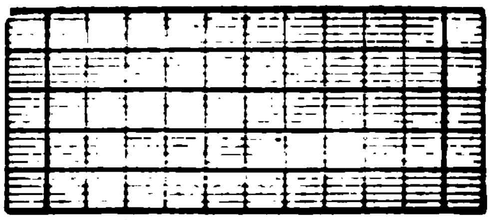

Fig. 47

Vertical and Horizontal Scale. The same horizontal scale is used as that in making the plan. The vertical scale is made larger so that the details of the profile are more clearly brought out. If a horizontal scale of 40 ft to 1 in is used, the vertical scale is usually 8 ft to 1 in. If the horizontal scale is 50 ft to 1 in, the vertical scale is 10 ft to 1 in. If the horizontal scale is 100 ft to 1 in, the vertical scale is 20 ft to 1 in. In other words, the vertical scale is usually five times greater than the horizontal scale.

Tracing. When the profile is drawn on the same sheet as the plan it is usually also traced on the plan tracing. When some form of standard transparent profile paper or cloth is used blue-prints can be prepared directly from these drawings. The prints may be made in long rolls and then cut into sheets of a convenient size for field use.

23. Mapping Cross-Sections

The Cross-Sections are mapped from the cross-section levels usually on some standard form of profile or cross-section paper. Sometimes, however, when the sections have only been taken at infrequent intervals, they may be drawn on the same sheet as the plan and profile, but this method is not recommended. The points in any cross-section are plotted to the desired scale with reference to one of the vertical lines of the paper as a transit line and one of the horizontal lines whose elevation is assumed. The plotted points are joined together by straight lines. The station number and elevation of line from which the points were plotted are written below each plotted section (see Fig. 48). The cross-sections should be checked and inked. Another method of mapping the cross-sections is to lay a sheet of tracing paper over a piece of cross-section or profile paper and plot the points on the tracing paper, the piece of engraved paper underneath serving as the scale. This method involves less expense for paper, the plotting can be just as quickly done, and if the areas are to be determined by planimeter, the estimating can be done as rapidly. The tracing paper, however, is more susceptible to changes in dimension which become apparent if final cross-sections are plotted on the original cross-sections. This same trouble would not occur if the sections are plotted on the profile or cross-section paper itself. Where contour lines have been run, cross-sections may be drawn by taking a section at right angles to the transit line at any point and plotting the contour elevations at their respective distances out on this section line from the transit line.

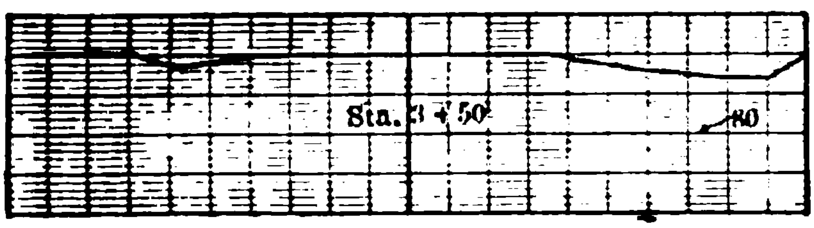

Fig. 48

Cross-Section Paper may be obtained in rolls engraved with squares 10 by 10 or 8 by 8 to the inch with the engraving 20 to 30 in wide. It is also

made in sheets about 16 by 20 ruled in squares 16 by 16, 12 by 12, 10 by 10, 8 by 8, 5 by 5 to the inch. All of these standard rulings are printed on tracing paper and some may be obtained on tracing cloth. When a scale of 4 or 5 ft to the inch is adopted, Plate A or Plate C profile paper is convenient to use.

The Vertical and Horizontal Scale is made the same in plotting the cross-sections. More accurate estimates of earthwork can be made if a large scale is used, hence a scale of either 4 or 5 ft to the inch, for ordinary conditions, is recommended. A scale of 10 ft to the inch is sometimes employed, but it is too small unless the cuts and fills are going to be extremely heavy as in railroad work when the use of a small scale may be warranted.

Blue-Prints of the cross-sections are made in the same manner as blue-prints of profiles are prepared.

24. Topographical Maps

A Topographical Survey, if based on a system of triangulation, is mapped by first plotting the triangulation points. If the area is a small one like that of a city, the convergence of the meridians may be neglected and the triangulation points are plotted by means of their rectangular coördinates. The drawing for this purpose is ruled off into large squares.

If the area is extensive like that of a state, the POLYCONIC method of projection is used to plot the meridians and parallels of latitude and the triangulation points are then plotted by means of their latitudes and longitudes. The parallels and meridians everywhere intersect at right angles. Tables giving coördinates of curvature are indispensable for laying off the parallels and meridians for polyconic projection. Extended tables in meters will be found in Appendix No. 6 of the Report of the U. S. Coast and Geodetic Survey for 1884 and a similar one for the English system in Woodward's Geographical Tables published by the U. S. Smithsonian Institution.

When the triangulation points have been plotted, the closed traverses may be drawn on the map and the topographical detail filled in by methods previously described. A topographical map of a city should show contours at an interval not greater than 5 ft.

Mounted Paper is used more extensively for mapping surveys of this character than any other. It is manufactured in sheets or rolls of varying widths and is less susceptible to changes than the plain drawing paper.

Scales Used. There is a wide variation in the scales used in preparing topographical maps, depending upon the purpose for which the map is to be used. A map for a city survey, if drawn to a scale of 200 ft to the inch, makes it possible to represent a large area on a sheet of practicable size and have the topography in sufficient detail for purposes of study. Sectional plans can be made of any portion of the map to as large a scale as desired in working out details for any locality. Scales as large as 40 or 50 ft to the inch are convenient for this purpose, altho a scale as large as 20 ft to the in is sometimes used. The field maps of the U. S. Coast and Geodetic Survey are usually plotted on a scale of $\frac{1}{10000}$, while some special maps are plotted with a scale of $\frac{1}{2000}$. The U. S. Geological Survey uses a scale of $\frac{1}{50000}$ in plotting their field maps.

Maps for an Extensive Area can be reproduced to a very small scale by means of photo-lithography so as to be contained on a sheet of convenient size. In this process the maps of the area are plotted and combined into

a number of sectional maps. These sectional maps are then photographed and the negatives of the different maps are carefully matched together and lithographed. The scale of lithograph maps of the U. S. Geological Survey is $\frac{1}{62500}$ or $\frac{1}{125000}$, the first being nearly equivalent to 1 mile to the inch.

25. Photo Printing

Photo Printing is a process for copying drawings by means of light in a similar manner that prints are made from a photographic negative. There are two different processes in general use as follows: Blue-print, negative, white lines on blue background; black line or blue line print, positive, black or blue lines on white background.

Blue-Prints. The drawing must be made with ink on some transparent material, usually tracing paper or tracing cloth. The drawing is placed inked side up over a sheet of sensitized paper or cloth. Both sheets are then placed in a printing frame with the drawing uppermost and exposed to sunlight or a strong artificial light for a short period. The length of exposure will depend upon the kind of paper used and the strength of the light. After proper exposure the printing paper or cloth is removed from the frame, washed thoroly in water and hung up to dry. All marks on the drawing will show white on the print, the remainder of the print being blue. A blue-print is called a negative print since it is like the photographic negative in that the light and dark colored parts of the print correspond to dark and light colored parts of the object.

Black or Blue Line Prints. The tracing is placed inked side down against a specially prepared sheet of sensitized paper in a printing frame and exposed to the light as in the former case. The sensitised paper is then washed in water for 5 min, in a solution of hyposulphite and water for 5 min and again in clear water for 20 min. The drawing will then appear on the sheet as white transparent lines on a brown background. This sheet when dry may then be used as any ordinary tracing to make either blue line prints or black line prints in the same manner that blue-prints are made and on a similar kind of sensitized paper.

Printing Machines are used in large offices instead of the ordinary printing frames. Essentially the machines consist of a cylindrical glass shell around which the drawing and sensitized paper are wrapped and held in place by a curtain. Light is furnished from a strong electric light. There are different styles of these machines some of which are limited as to the size of drawing they will accommodate. Some styles are adaptable for making prints of a width equal to the widest rolls of paper and of a length limited only by the length of paper in the roll.

GRADES, VERTICAL CURVES, CROWNS AND ESTIMATES

26. Establishing the Grade

Determining the Grade. Factors which have to be considered in determining the finished grade of a road or street are discussed in Sects. 4, 6 and 7. The profile, plan and cross-sections should be carefully studied with these points in mind. Some points will be determined on the profile which the center line grade must meet. The problem is then to establish a grade line that will conform to these limiting points and satisfy the other considerations. It is generally desirable to obtain a grade such that the cuts and fills will balance. Other considerations, however, may be so important

as to make the balancing of the cuts and fills impractical or uneconomical. The best way to fit a grade line to the profile after the limiting points have been established is to take a piece of thread and use it as the grade line instead of drawing trial lines on the paper. Different positions of the grade line can be examined by stretching the thread between different points and moving one end or the other up or down. In this way a number of different grade lines may be examined without drawing any lines on the profile. Each line may be studied with reference to how it fits the plan and cross-sections at critical points. A grade line is finally found by this trial method that seems best to fit the conditions imposed. This line is drawn on the profile in pencil and the elevations of the grade line intersections and the rates of grade between intersections are calculated. On road plans it is not necessary to figure grade elevation or rates of grade closer than hundredths, whereas on street plans the computations may have to be carried to thousandths.

N. Y. State Highway Comm. Rules. "Grade lines shall be drawn only after careful consideration of all the data available, and shall be adjusted until the desired result is obtained. The following should be carefully considered:

1. The recommendation of the inspection notes.
2. The relative importance of the highway; the character of the traffic; and the direction of the heavy traffic, the maximum grade not necessarily being the same in both directions.
3. Drainage.
4. The character of the soil and old road-bed.
5. Houses, shade trees, intersecting driveways, etc.
6. The avoidance, wherever practicable, of reverse grades on long hills.
7. The distorted scale of the profile.

"Maximum grade is to be determined for each highway separately and all controlling features must be taken into consideration. It shall be referred to the Division Engineer if greater than 7% is necessary. In general, adverse grades and grades less than 200 ft long, should be avoided. Grades should be kept down to 5% where possible, to avoid paving the gutters. When a 5% is not feasible, in most cases it would be economical to increase at once to a 7% unless the highway has already been graded to some intermediate rate. No 7% grade should be allowed less than 300 ft long unless one end is fixed by some unchangeable structure, as a large bridge or railroad grade crossing.

"Except in very flat country where the excavation is naturally light, railroad grades with long tangents should be avoided as they usually require long shallow cuts and fills, both of which are undesirable, the former on account of unnecessary excavation, the latter because of the danger of requiring extra foundation. Long fills may, however, be made where recommended by inspection either to raise above highwater mark or to obviate the need of stone sub-base. Care should be taken in raising the roadway at either end of a bridge or at either side of a large culvert, that the structure be not endangered by the closing of flood channels. In all such cases where the roadway is liable to flood, level grades are required; they will not be permitted under any other conditions. Where the roadway grade is less than 0.4%, the gutters should be graded independently of the roadway so as to have the 0.4% grade as a minimum.

"It is desirable to place the pavement without breaking up the present traveled road-bed, and with as little filling as possible, if a reasonably smooth grade can be obtained while so doing.

"Changes in rate of grade of more than 2% should be eased by vertical curves of 100 to 300 ft in length according to conditions. Tangents between vertical curves opposite in direction, should not be less than 100 ft in length. As far as practicable rates of grades should be established exactly at even tenths percent. The middle correction for vertical curves may be figured by the formula $\frac{G2 - G1}{8} \times \frac{\text{LENGTH}}{100}$, $G1$ and $G2$ being the rates of the two intersecting grades; intermediate corrections vary as the square of their distance from the nearest end of curve."

The Rate of Grade is its rise or fall in feet for a length of 100 ft and is usually expressed as a percentage thus: 3.84% rise, meaning that the line rises 3.84 ft for every 100 ft of horizontal distance. Rising grades are also described as up or + grades; falling grades as down or − grades. Table VIII (13) shows the increased distance in surface measurement over horizontal distance for the several grades for each 1000 ft.

Table VIII

Percent of Grade	Distance	Percent of Grade	Distance
1.0	1000.05	8.0	1003:19
1.5	1000.11	8.5	1003.59
2.0	1000.19	9.0	1004.04
2.5	1000.31	9.5	1004.50
3.0	1000.45	10.0	1004.99
3.5	1000.61	10.5	1005.49
4.0	1000.79	11.0	1006.03
4.5	1001.01	11.5	1006.59
5.0	1001.25	12.0	1007.17
5.5	1001.51	12.5	1007.78
6.0	1001.79	13.0	1008:41
6.5	1002.11	13.5	1009.07
7.0	1002.44	14.0	1009.75
7.5	1002.80	14.5	1010.46
		15.0	1011.18

For road plans it is customary to change the rate of grade at some 50 or 100-ft station and to adjust the elevations so that the rate of grade is divisible by two, which considerably facilitates the computations when the grade has to be figured for each 50-ft station.

On street plans it is customary to make the grade a uniform rate between two streets unless such procedure would result in a flat grade or the topography is such as to prevent it being done. Adjusting the elevations of the grade table at street intersections will also cause some modification of the grade between the intersection of the center lines of the streets and the building lines. The grade points will frequently come at odd stations and necessitate figuring the grades to the nearest thousandth of a foot in order to make the computations correct.

After the uniform rates of grade have been calculated, vertical curves are figured as described in Art. 27 and drawn on the profile where necessary. Grade elevations at intersecting roads or streets are calculated as explained in Art. 27. On road plans the center line grade of finished road is drawn in on the profile. Sometimes the grade elevation for each station is placed vertically above the station and above the ground line. Another and more common method is to give the rates of grade where they are uniform for a distance of 100 ft or more and to give elevations for all stations of vertical curves and points of intersection of grade lines. Fig. 49 represents the last method of recording the grade on the plan. On street plans the grade line of the center of the street may be shown on the profile or the grade

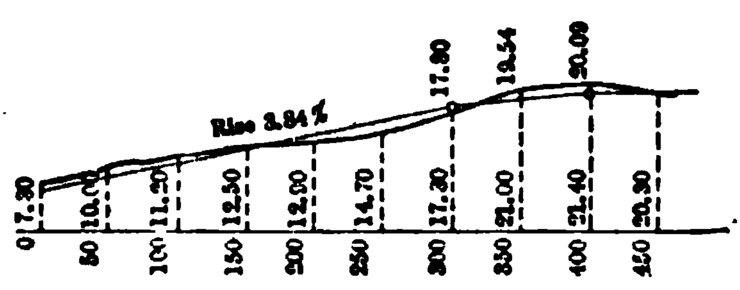

Fig. 49

line of the curbs on either side of the street may be shown (see Fig. 50). The description of the grade may be made in a similar manner to that of road plans. At properly designed street intersections, however, some of the elevations around the intersection will have to be written on

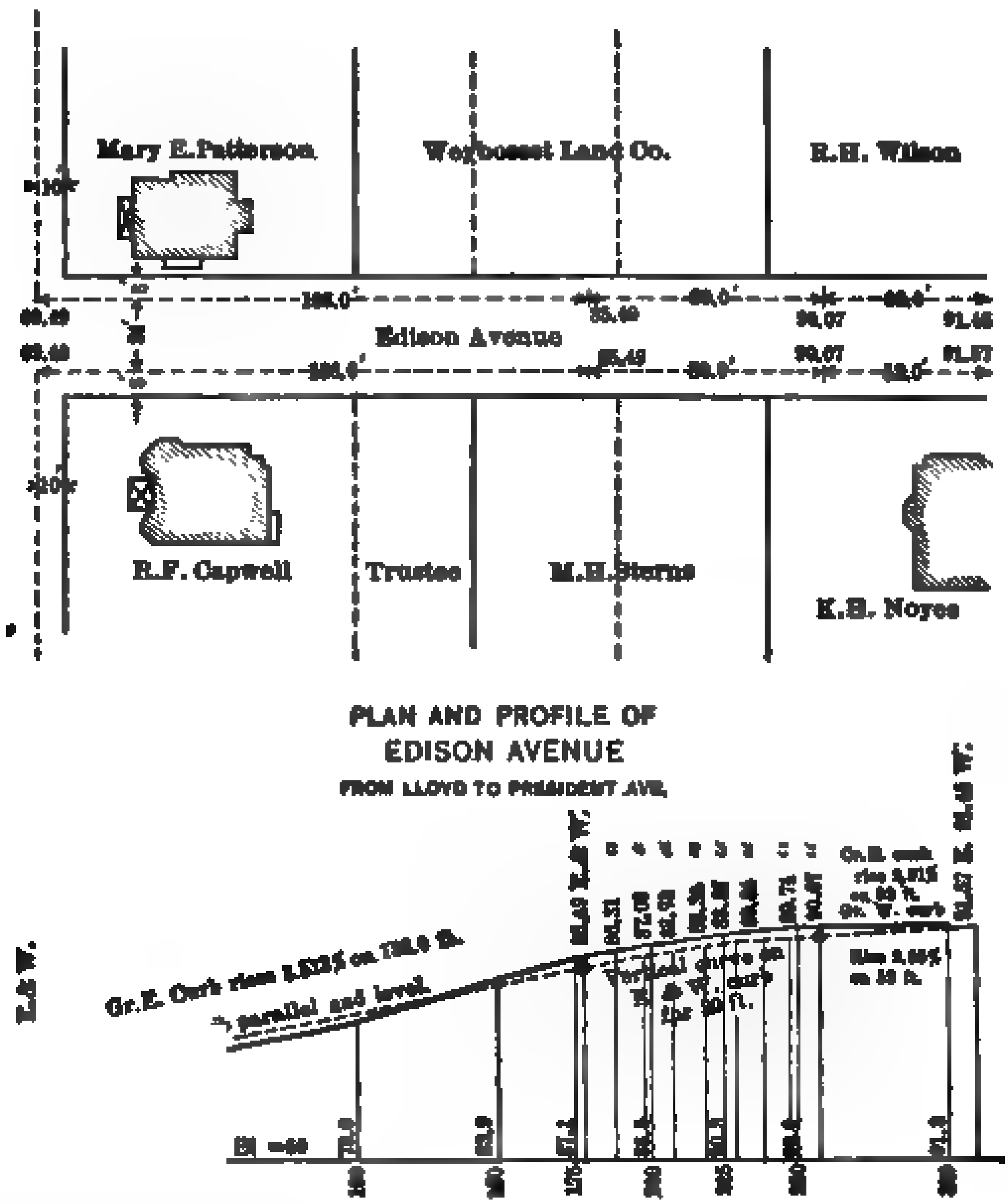

Fig. 50

the plan of the intersection in order to show completely the proposed improvement.

The Scale Used in plotting the grade is the same as the scale of the profile on which it is drawn.

Ill. State Highway Comm. Experimental Scales (21). "The regular scale for profiles is, 1 in equals 8 ft vertical and 1 in equals 80 ft horizontal, or a distortion of horizontal to vertical of 10 to 1. This scale works in exceptionally well with the filing system and it was hardly thought necessary at this time to consider changing this scale. However, there was worked up in the office, grade line and earthwork computations on 53 Stations of road on Route 5 Moultri County. This road was to be 10 ft concrete slab in the center and 10 ft earth shoulders on each side, making a total width of graded

road of 30 ft. When this grade line was plotted using the regular scale quantities for the 53 Stations there were 3174 cu yd of earth excavation in cut. After two or three weeks the same man plotted this profile on a scale 1 in equals 8 ft vertically but changing the horizontal scale so that 1 in would equal 16 ft, making the distortion between the horizontal and vertical scales only 2 to 1. He replotted this grade line and computed quantities of excavation and the cut amounted to 2831 cu yd, showing a saving of 643 cu yd of excavation by using the more nearly natural scale. This road is on gently rolling country and black loam soil. The reason, of course, for the difference in the two methods is due to the fact that when the scales are so greatly distorted it is a constant temptation for the men plotting the grade line to want to cut off every bump that appears on the ground line. When the scale is plotted to more nearly natural scale the men see that the grade could be laid along the ground practically as it is without causing any bad effects after the road is constructed. It is not practical, of course, to make the regular plans on as nearly a natural scale as this experiment was conducted. It is, however, perfectly feasible to plot the profile a second time, using this natural scale and replot the grade line after it had been established and quantities computed. Granting that there might not be any saving in time of the computations of quantities in computing the grade line, it would not take more than two man-hours' extra work to use the two scales than it would the one, and there would certainly be a big saving in the amount of excavation."

An Estimate of Quantities is made for the established grade. If this estimate is not satisfactory, the grade is revised and other estimates made until the desired conditions are fulfilled.

A Field Examination of the grade is of the utmost value. Before the final adoption of a grade line, an examination of the established grade should be made on the ground of the proposed improvement. Information, which cannot be obtained from the survey notes, may be obtained in this way which makes a revision of the grade advisable.

N. Y. State Highway Comm. Practice. "Before commencing an inspection, the information obtained by the survey party should be reviewed, and note made of any failure to secure full information. The kind and location of available road material should be investigated thoroly, the data obtained by the survey party fully checked, and all possible additional data procured. Unless a blue-print of the plans can be obtained, the profile and transit notes must be carried on all inspections, and all inspection notes must be entered in the back portion of the book. The inspection shall be made by walking over the highway, using a conveyance only to arrive at or leave the highway.

"Recommendations must be made in every case in regard to the following matters:

1. The kind and width of pavement and the typical section to be used in improving the highway.

2. The location and size of all new culverts and ditch crossings, and the action to be taken in each case regarding old culverts. It must be remembered that except in free-percolating soils the desirable maximum length of drainage accumulations in the gutters is about 900 ft. Outlets for gutters should be provided as frequently as practicable; where a new culvert will have to be and can be built to provide such outlet, it should be so placed as to care for 600 to 900 ft of roadway in either direction.

3. The change necessary or advisable in the new grade line as drawn on the profile.

4. The advisability of acquiring additional land to improve the alignment, and exceptionally full information if an additional survey will be required.

5. The condition of existing retaining walls and advisability of retaining, rebuilding, replacing with slope wall or new concrete wall.

6. The location of all necessary under drains, telford base or sub-bottom, with statement as to the kinds available, deep ditches, or other construction necessary to secure a firm subgrade.

7. The need of cobble gutters in violation of the regular 5% rule because of soil conditions, that is, cobble gutters needed on 5% or under, and where they may be dispensed with on grades over 5%, and whether the soil requires cement joints.

"The desire of the local county and town superintendent in regard to the nature of the improvement must be learned and recorded. Consultation with prominent resi-

dents along the line of the highway is advisable, and a statement of their opinion should be received and noted."

Mass. State Highway Comm., Division Engineer's Report. "These plans, profiles, and cross-sections are then sent to the division engineer in whose division the improvement is projected. The division engineer studies the proposed changes in grade and alignment on the ground, and then makes a preliminary report to the chief engineer on a standard printed form. This report consists of six foolscap sheets, joined at the top, designed to be folded and filed, 4 by 8½ in. After noting the date of the receipt of the plans, and of the examination of the road, the division engineer fills in the following printed queries and explanations:

1. Present road surface, character of.
2. Surface sections and alignment, discussion of. Division engineers are expected to recommend the section of broken stone which will be most economical and satisfactory in each case. It is not necessary that the same section shall be adopted thruout the entire length of the road. When a change in section will result in a saving of stone by taking advantage of existing conditions, such a change should be recommended.
3. Location lines, discussion of. If changes can be made so as to avoid unnecessary land damages, division engineers are expected to recommend them.
4. Grade submitted, discussion of, with recommendations.
5. Street railway tracks. Division engineers will state whether the present alignment and grade are satisfactory, and if not, what changes are necessary.
6. Borrow and gravel, material suitable for, location and quality of. Give sufficient data to permit approximate estimate of overhaul.
7. Culverts, bridges and catch basins. All structures with a span greater than 8 ft will be classed as bridges. Division engineers will give such information as they can secure concerning drainage areas. When it appears to be necessary to obtain easements for the discharge of culverts on private land, mention should be made of the matter under this heading.
8. Bituminous treatment, discussion of.
9. Foundations and drains, recommendations concerning.
10. Guard rail, recommendations as to location of.
11. Trees, value of, for shade.
12. Ledge and other materials, not otherwise enumerated.
13. Prices recommended for use in the preparation of the estimates and contracts. Here follows a list of operations and materials with price per unit: Excavation, earth; excavation, borrow, not including overhaul; excavation, ledge; masonry; concrete, not including cement and steel; gravel; broken stone on cars; broken stone on roads; unloading stone; stone at crusher; breaking stone; teaming stone; spreading stone; watering stone; rolling stone; supervision; total for broken stone; bituminous treatment, not including bituminous material; various sizes of culvert pipe; guard rail; stone filling in place; cobblestone gutters; delivering and setting bounds; catch-basins, not including frames and grates.
14. Provisions for taking care of travel during construction.
15. Remarks.

"This scheme, as readily perceived, gives adequate information to the Commission and to the engineers in the main office, where specifications and contracts are drawn. Ample information regarding kind, character and method of improvement it is desirable to make is given so that final plans, profiles and specifications may be drawn that will properly fit the local conditions."

27. Vertical Curves

A Vertical Curve is a parabolic or circular curve drawn tangent to two intersecting grades so that the transition from one rate of grade to another will not be abrupt. The form of curve most generally used is the parabola. The length of curve varies depending upon the algebraic difference in the rates of the intersecting grades. Experience has proved that the following lengths will make satisfactory curves: 100 ft, 200 ft, 300 ft for algebraic differences in grades between 1 and 3, 3 and 6, and more than 6 respectively.

Constructing the Curve. In Fig. 51 let $a\,b$ and $b\,c$ be two grades intersecting at b. The curve is tangent to the two grades at m and n. Draw the chord $m\,n$. The horizontal distances between m and o, o and b, b and p, p and n are equal and correspond to the station interval. The vertical curve $m\,e\,n$ is a parabola, x and y are the abscissa and ordinate respectively of any point on the curve measured from e as an origin, with the tangent to the curve at e as one of the coördinate axes. The ordinate y is always expressed as a fractional part of $f\,m$ or $f\,n$ and the abscissa $x = y^2 \times e\,f$. The elevation of f is the mean of the elevations of m and n, and e is half way between b and f. The point e is thus located. Draw the tangent

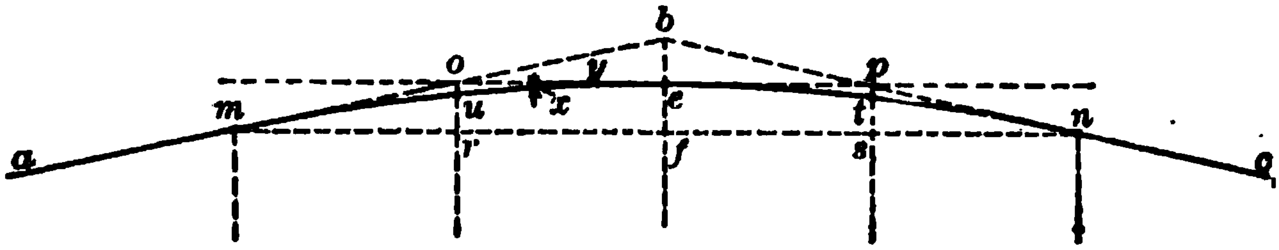

Fig. 51

to the curve thru e. It will be parallel to $m\,n$. For point u, $y = o\,e/m\,f = \frac{1}{2}$ and $x = y^2\,e\,f = \frac{1}{4}\,e\,f$. The distance $r\,u = e\,f - x = \frac{3}{4}\,e\,f$ laid off from r on the chord $m\,n$ locates u. The point t is located in a similar manner. The curve is drawn by connecting the points m, u, e, t, and n. If points are calculated for 50-ft intervals along the curve, they may be connected by straight lines without appreciable error. A slight error is involved in practice because the coördinates y and x are measured parallel to a horizontal and vertical axis thru e. The difference between these coördinates and those parallel and perpendicular to the tangent thru e is so small, however, that it can be neglected.

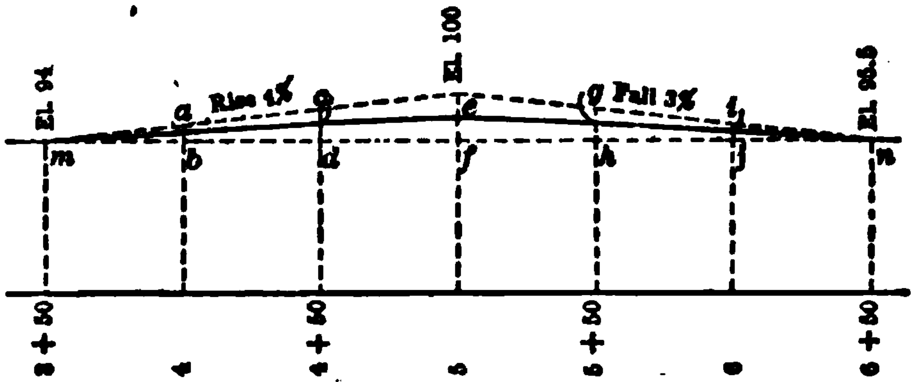

Fig. 52

Example. Compute the vertical curve elevation at each 50-ft station for a rising 4% grade and a falling 3% grade which intersect at Sta. 5 at an elevation of 100. The algebraic difference in grades is 7 and hence a 300-ft curve is required. The points of tangency will then be 150 ft either side of the intersection. The computations are given below for different points of the curve as shown in Fig. 52.

Elevation at f = (94 + 95.5)/2 = 94.75 ft
Elevation at e = (100 + 94.75)/2 = 97.37 ft, ef = 2.62 ft
Coördinates for c and g, $y = 1/3$, $x = 1/9 \times 2.62 = 0.29$ ft
Coördinates for b and j, $y = 2/3$, $x = 4/9 \times 2.62 = 1.16$ ft
Then $c\,d = g\,h = e\,f - 0.29$ ft $= 2.33$ ft and
$a\,b = i\,j = e\,f - 1.16$ ft $= 1.46$ ft.

Elevation at m	= 94.00 + 0	= Elevation of curve at Sta. 3 + 50	= 94.00
Elevation at b	= 94.25 + 1.46	= Elevation of curve at Sta. 4	= 95.71
Elevation at d	= 94.50 + 2.33	= Elevation of curve at Sta. 4 + 50	= 96.83
Elevation at f	= 94.75 + 2.62	= Elevation of curve at Sta. 5	= 97.37
Elevation at h	= 95.00 + 2.33	= Elevation of curve at Sta. 5 + 50	= 97.33
Elevation at j	= 95.25 + 1.46	= Elevation of curve at Sta. 6	= 96.71
Elevation at n	= 95.50 + 0	= Elevation of curve at Sta. 6 + 50	= 95.50

The above calculations can be simplified and the same results obtained by measuring the offset from the grade tangents produced instead of the chord $m\,n$. Calculate $e\,f$

as above, then $ef = 2.62$ ft. The offsets from the grade tangents produced to the curve at a and i are each $1/9\ ef = 0.29$ ft, since $mb = 1/3\ mf$ and offsets from the grade tangents produced to c and g are each $4/9\ ef = 1.16$ ft since $md = 2/3\ mf$. The remaining calculations are tabulated below.

Sta. 3+50	Elevation grade tangent = 94.0	Elevation of curve = 94.00
Sta. 4	Elevation grade tangent = 96.0	Elevation of curve = 96.0 − 0.29 = 95.71
Sta. 4+50	Elevation grade tangent = 98.0	Elevation of curve = 98.0 − 1.16 = 96.84
Sta. 5	Elevation grade tangent = 100.0	Elevation of curve = 100.0 − 2.62 = 97.38
Sta. 5+50	Elevation grade tangent = 98.5	Elevation of curve = 98.5 − 1.16 = 97.34
Sta. 6	Elevation grade tangent = 97.0	Elevation of curve = 97.0 − 0.29 = 96.71
Sta. 6+50	Elevation grade tangent = 95.5	Elevation of curve = 95.50

28. Street and Road Intersections

Street Intersections. The calculation of grades at street intersections will be considered in Sect. 7. Elevations should be figured not only for the center lines of the intersecting streets but also for the curb lines and building lines near the intersection so that proper transverse sidewalk slopes result. If the design is properly worked up, all elevations around the intersection are definitely established and they should be written on the plan of the intersection. Unless an intersection is completely designed and all elevations definitely fixed by some standard method, more or less confusion will result on account of the different elevations obtained for the same corner by using in the computations first the rate of grade of one street and then the rate of grade of the intersecting street.

Road Intersections. Where there is any possibility of a locality becoming closely built up, it would be advisable to work up the grades at the intersection in the same manner as for street intersections. A large percentage of the roads, however, run thru districts that probably never will be thickly settled. In such cases the grade of the improved road is established so that an easy approach to it may be had from the intersecting road. The intersecting roads are often unimportant roads infrequently traveled and hence do not have to be given much consideration. The profiles taken in the survey for short distances along each intersecting road when plotted on the cross-sections or profile, may be studied with reference to the new grade of the main road. By cutting and filling for short distances on the intersecting roads, the grade may be changed so as to make a satisfactory approach to the new grade of the main road.

At the intersections of the more important roads the best grade can be determined by staking out the grade planned in the office and then changing it on the ground so as to best fit the requirements. The plan grade is then made to agree with the grade on the stakes.

29. Crown Formulas

The Crown of a Roadway is the difference in height between the grade of the center and the grade of the sides at the edge of the shoulder, edge of gutter, or at the curb line. The mean transverse slope is the crown divided by half the width of roadway over which the crown is applied.

Fig. 53

The cross-section of the roadway surface may be formed by two straight lines meeting at the center, or it may conform to a circular or parabolic arc or to two flat circular arcs meeting at the center (see Fig. 53). Numerous formulas have been derived by which the amount of crown can be found. See (30), (43) and (44). In some formulas, the kind

of pavement, grade of highway, variation in heights of curbs, are considered factors which affect the crown. A few formulas give rules for distributing the crown.

The Andrew Rosewater Formula is as follows: $c = w\,(100 - 4p)/6000$ for brick, stone block, wood block and compressed European rock asphalt, and $c = w\,(100 - 4p)/5000$ for American sheet-asphalt; in which c represents the crown of pavement in feet at the center, w the distance between curbs in feet, and p the grade of street expressed as a percent, thus, if grade is 4%, $p = 4$. Elevations for other points thruout the width of the street are found by assuming the curve to be a parabola and figuring the ordinates to the curve by the following formula: $y = c\,x^2/a^2$ in which c represents the crown at the center in feet, a the half width of roadway in feet, x the distance out in feet from the center to the point whose elevation is to be found, and y the decrease in crown in feet for a point a distance x from the center.

Warren's Rules are very practical and easy to apply.

For pavements having smooth surfaces such as sheet-asphalt, creosoted blocks, and grouted stone blocks and brick, and having a grade of 2% or less, with no car tracks, make the crown 1 in to each 6 ft of width between curbs.

For pavements providing more secure foothold, such as stone blocks and brick, having bituminous joints, broken stone or Bitulithic on streets having a 2% or less grade, make the crown 1 in to each 4 ft of width.

If a street has car tracks, deduct the total width outside to outside of rails from the width between curbs and divide the difference, double width between track and curb, by 6 and 4 respectively.

For grades between 2% and 4%, provide ½ the crown provided by the above computation. For grades above 4%, provide a crown ⅓ that of the above computation.

Distribute the crown as follows: Drop ⅛ the crown at the crown mid quarter point; drop ⅛ the crown at the quarter point; drop ⅝ the crown at the curb mid quarter point. By quarter point is meant the point midway between the center of the carriageway and the curb, or, in the case of streets on which car tracks are placed, it is the point midway between the outside rail and curb.

Dare's Formula has been largely used for computing crowns in Washington, D. C., and is applicable for all widths up to 50 ft:

$$c = w\,(100 - 4\,p)/6300 + 50\,p^2$$

in which c represents the crown in inches, w the width of roadway in inches, p the grade expressed as a percent, that is for a 4% grade, $p = 4$. The distribution of the crown, where curbs are level, is obtained by the formula $8\,c/0.3\,w = d$ in which c represents crown in inches, d the transverse grade expressed as a percentage, and w the width of roadway in feet. The transverse grade from quarter point to gutter is made just twice as steep as it is from the center to quarter point. The elevations at points e, f and g in Fig. 54 are as follows:

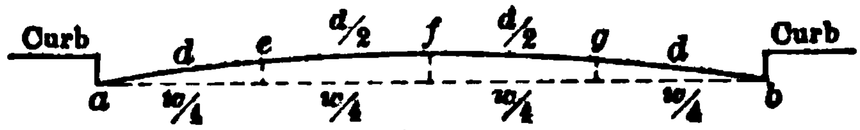

Fig. 54

Elevation at e or g = a or $b + \dfrac{c}{18}$ Elevation at f = a or $b + \dfrac{c}{12}$

a and b are the elevations at the gutters in feet and hundredths of a foot and c is the crown in inches.

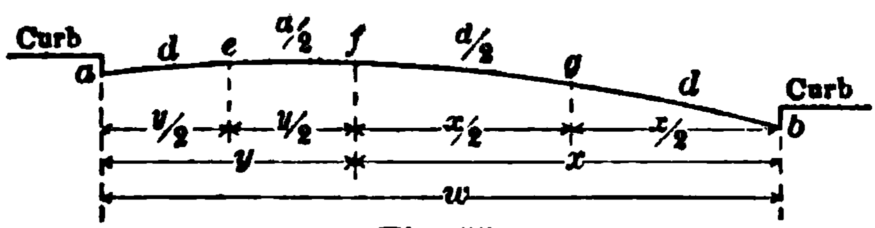

Fig. 55

For Curbs at Different Elevations, the crown obtained by Dare's formula is distributed as follows: In Fig. 55 let letters have the same significance as before, x represent the distance in feet from low curb to high point of cross-section, and y the distance in feet from high curb to high point of cross-section:

$$x = (a - b)/1.5\,d + w/2$$

In this formula and in those given below d is expressed in hundredths of a foot:

Elevation at $g = b + x\,d/2$

Elevation at $f = b + 3\,x\,d/4 = a + 3\,y\,d/4$

Elevation at $e = a + y\,d/2$

Mean Transverse Slopes. The cross-section of state highways of standard widths of hardened surfaces, varying from the minimum up to about 20 ft, are commonly made to conform to two straight lines intersecting at the center. These lines have the same slope as the mean transverse slope. If s equals mean transverse slope, expressed as inches of rise to each foot of half width, c the crown in inches and w the width of roadway in feet, then $s = 2\,c/w$. The slope s is usually assumed and the amount of crown determined from it by solving for c in the formula.

Example. If the slope of the surface is $^3/_4$ in to the foot for a 14-ft road, the crown at the center will be $c = w\,s/_2 = {^3/_4} \times {^{14}/_2} = 5^1/_4$ in.

30. Estimating Quantities

When the grade of the highway has been established and the form of cross-section adopted, an estimate of the earthwork can be made.

Subgrade Elevations on the center line for each station are determined from the center line grade elevations by subtracting from the latter the distance from the finished grade to the subgrade on the center line. The subgrade elevations are then plotted on the cross-sections at each station on the line corresponding to the finished center line. A template of the same form as the finished cross-section of the highway up to subgrade and made to the same scale as that of the cross-sections is prepared (see Art. 4). The finished section of road for grading is then plotted on the cross-section at each station by placing the template on the cross-section in a horizontal position with the upper edge of the center point of the template coincident with the plotted elevation of the subgrade. A line is drawn around the template and the side slopes of the banks drawn so as to intersect the ground line of the original cross-section. The area between the lines of the finished section and the original cross-section is in cut if below the ground line of the original cross-section and in fill if above.

Areas in Cuts and Fills are determined by means of a planimeter, by dividing the areas into approximate geometrical figures and computing the same, by counting the ruled squares on the paper included in the area, and by scaling and adding the ordinates between the original ground line and the finished section for each foot of width of the finished section.

In Using Planimeters to determine the areas, a double run of the area is made for check purposes. The planimeter reading at the end of the second run should be twice that at the end of the first. Another method of checking planimeter work is for two men with different planimeters to determine the areas independently of each other. Two separate estimates are made from the two sets of planimetered areas and the results compared. In some offices, if the two estimates do not agree within 2%, the areas are planimetered a third time.

The Count Method is usually made by two men working together, each checking the other. Each man estimates the area by counting the squares between the finished and the original cross-sections. Knowing the number of squares and the scale of the drawing, the area is known. Neither man announces the result of his count until the other has finished. If they do not agree a recount is made until agreement is reached. This method is very rapid and accurate results can be obtained by men who are trained to the work, if the sections are plotted to a scale of 4 or 5 ft to the inch. A person may get used to estimating in this way by counting the squares and then running over the same area with the planimeter and comparing results.

In the Scaling Method the ordinates may be scaled and added or a pair of dividers may be used and so manipulated that the distance between the points, when each vertical for each foot of width has been spaced off, will represent the total sum of these verticals. The area is this distance measured to the same scale with which the cross-sections were plotted.

Three and Five-Level Sections. Areas may also be computed directly from the field notes in some cases without plotting them. This is the case of three-level and five-level sections, information for which is obtained in the field in setting slope stakes (see Art. 18). Let Figs. 56 and 57 be sections in which the elevations of points, on the ground where slopes run out and at other places as indicated in the figures, have been determined in the field. Fig. 56 shows a three-level section and Fig. 57 a five-level section or one in which the elevation of two other points besides the center and slope points have been taken.

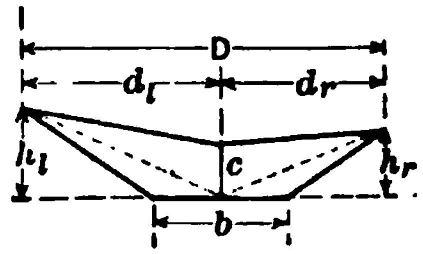

Fig. 56 (3)

Area for a three-level section, $A = \frac{1}{2}\,[\frac{1}{2}\,b\,(h_r + h_l) + c\,D]$; For a level section $h_r = c = h_l$, and $A = c\,(b + s\,c)$; Area for a five-level section, $A = \frac{1}{2}\,(c\,b + e_r\,d_r + e_l\,d_l)$; c represents the center height, s the slope, h_r and h_l the side heights, d_r and d_l the side distances, and $D = d_r + d_l$.

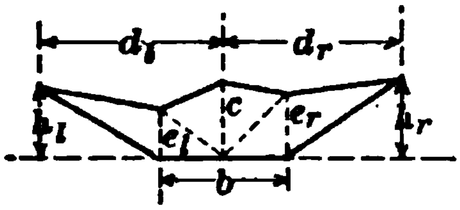

Fig. 57 (3)

It is not necessary to estimate areas closer than the nearest square foot. The areas at each 50 or 100-ft station and at those stations between the regular station intervals, which mark abrupt changes in the slope of the ground, are determined. It is convenient to tabulate the areas on blank forms ruled off into columns for this purpose, the columns being headed Station, Area Cut, Area Fill.

Determination of Volume. The volume is determined from the areas by the prismoidal formula, or by the average end area formula with or without a prismoidal correction being applied. See (1), (4) and (14).

The Prismoidal Formula is $v = 1/6\,l\,(a_1 + 4a_m + a_2)$ in which a_1 and a_2 are the areas in square feet of two adjacent sections a distance l feet apart, v the volume in cubic feet and a_m an area which is computed from the mean of the dimensions of a_1 and a_2. Divide v by 27 to get the number of cubic yards. This formula gives exact volumes for all ordinary cases of earthwork. The work involved in using this formula is very great and hence it is not in common use for earthwork computations.

The Average End Area Formula is $v = \frac{1}{2}\,l\,(a_1 + a_2)$ in which the letters have the same significance as in the prismoidal formula. Divide v by 27 to get the number of cubic yards. This formula is easy to apply and is the one most used, tho it gives results that are too large. If the station interval is uniform the cubic yardage for any desired length of n stations can be found as follows: Let $a_1\,a_2\,a_3\,.\,.\,.\,a_n$ be the areas in cut or fill at the different stations at a uniform interval l apart, the total length between the first a_1 and the last a_n, being $L = n\,l$. If the areas are taken in square feet and L is in feet, the volume in cubic yards will be

$$\frac{a_1 + 2\,(a_2 + a_3 + \ldots\ldots\, a_{n-1}) + a_n}{2 + 2\,(n - 1)\;27} \times \frac{L}{27} \tag{17}$$

Table IX gives the volume in cubic yards of solids 100 ft long having mean areas varying from 1 to 100 sq ft. The yardage for any section is found as follows: Compute the mean area of the section by the first term in formula (17) to the nearest hundredth. Look up the volume in the table corresponding to this area, and multiply this value by the length of section in feet divided by 100. The volume in the table for any other area than those given is found by adding together the volumes for areas whose sum equals the area in question.

Example. Find volume for 100-ft length having an area of 306.52 sq ft:

Area	Volume
300.00	1111.11
6.00	22.22
0.50	1.85
0.02	0.07
306.52	1135.25 cu yd

Table IX.—Excavation and Embankment Quantities

Cubic Yards of Excavation or Embankment for Average End Areas Varying from 1 to 100 Sq Ft and a Length of 100 Ft

Area	Volume	Area	Volume	Area	Volume	Area	Volume
1	3.70	26	96.29	51	188.91	76	281.50
2	7.41	27	100.00	52	192.61	77	285.20
3	11.11	28	103.70	53	196.32	78	288.91
4	14.81	29	107.41	54	200.02	79	292.61
5	18.52	30	111.11	55	203.73	80	296.32
6	22.22	31	114.82	56	207.43	81	300.02
7	25.93	32	118.53	57	211.13	82	303.72
8	29.63	33	122.23	58	214.84	83	307.43
9	33.33	34	125.93	59	218.54	84	311.13
10	37.04	35	129.64	60	222.24	85	314.83
11	40.74	36	133.34	61	225.95	86	318.54
12	44.44	37	137.05	62	229.65	87	322.24
13	48.15	38	140.75	63	233.35	88	325.95
14	51.85	39	144.46	64	237.06	89	329.65
15	55.55	40	148.16	65	240.76	90	333.36
16	59.26	41	151.87	66	244.46	91	337.06
17	62.96	42	155.57	67	248.17	92	340.77
18	66.67	43	159.28	68	251.87	93	344.47
19	70.37	44	162.98	69	255.57	94	348.18
20	74.07	45	166.69	70	259.28	95	351.88
21	77.78	46	170.39	71	262.98	96	355.59
22	81.48	47	174.10	72	266.68	97	359.29
23	85.18	48	177.80	73	270.39	98	363.00
24	88.89	49	181.50	74	274.09	99	366.70
25	92.59	50	185.20	75	277.79	100	370.40

Prismoidal Correction is a volume expressed by the formula $1/12\, l\,(c_1 - c_2)(D_1 - D_2)$ in which l is the length between two end areas a_1 and a_2, c_1 and c_2 are the center heights in feet of a_1 and a_2 respectively, D_1 and D_2 are the horizontal distances in feet for a_1 and a_2 respectively between the points where the side slopes of the finished section intersect the ground line as shown in Fig. 56. If a volume is found by the average end area method and the volume given by the prismoidal correction formula subtracted from it, the result is approximately the same as if the prismoidal formula had been used. Therefore the volume in cubic feet may be computed by the formula:

$$v = \tfrac{1}{2}\, l\,(a_1 + a_2) - 1/12\, l\,(c_1 - c_2)\,(D_1 - D_2)$$

Dividing v by 27 gives the number of cubic yards. Table X gives values of the prismoidal correction in cubic yards for different values of $c_1 - c_2$ and $D_1 - D_2$ in feet when $l = 100$ ft. For any other length l_1 than 100 ft, the volumes in the table should be multiplied by the ratio of $l_1/100$. The volume by the end areas must be expressed in cubic yards before subtracting the prismoidal correction obtained from the table. For irregular sections c_1 is the height of a three-level section having an area equivalent to a_1 of the irregular section; c_2 is found from a_2 in a similar manner.

If the prismoidal formula or the average end area formula with prismoidal correction applied is used, it is necessary to compute the volumes for each interval between stations where cross-sections have been taken thruout the length of the work. The volumes in cut and in fill are figured separately and the sum of all the volumes in cut and the sum of all the volumes in fill give the total volume of cut and fill respectively. The volume must

also be found for each interval as above if a mass diagram is to be constructed. A rapid estimate of the total quantities may be made by the average end area formula by finding the volumes for a long section having a common station interval as per formula (17). In this method, however, where the regular station interval is interrupted by a plus station designating an abrupt change of slope, the volume in this interval will have to be figured separately.

Example. Areas have been found for Sta. 1, 1 + 50, 2, 2 + 50, 3, 3 + 20, 3 + 35, 3 + 50, 4, 4 + 50, 5. It is seen that the station interval is 50 ft from Sta. 1 to 3 and from Sta. 3 + 50 to 5. A rapid estimate of total volume from Sta. 1 to 5 would be found by adding together the volumes from Sta. 1 to 3, Sta. 3 to 3 + 20, Sta. 3 + 20 to 3 + 35, Sta. 3 + 35 to 3 + 50 and Sta. 3 + 50 to Sta. 5.

The Zero of Cut or Fill. Where a center line grade changes from a cut to a fill, it intersects the ground. This point c may be determined in the field by finding the station of a point on the center line where the ground elevation and grade elevation are the same. If the ground on a line at right angles to the center line at this station is the same elevation as the center, this station will be the true zero of the cut or fill. If the ground is sloping at right angles to the center line, the stations of two other points a and b in Fig. 58 as well as the point c on the center line have to be found. Points a and b on the edges of the road base correspond to points on the ground whose elevation is the same as grades at a and b. Cross-sections are taken at a, c and b in the regular manner. Points a and b will then be the stations of the true zero of the cut or fill. In the figure the area at a is zero cut and all fill, at c the area is part cut and part fill and at b is zero fill and all cut. See (1).

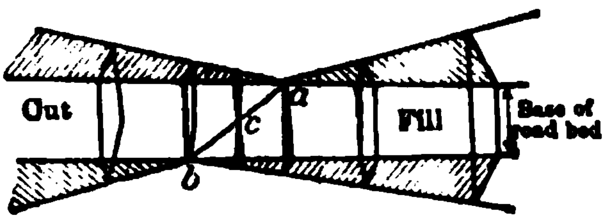

Fig. 58

Unless the earthwork is of great magnitude it is hardly necessary to determine the true zero of the cuts and fills. The station on the profile where the grade intersects the ground line may be taken as the zero of the cut or fill without great error. In cases where the station interval is 50 ft and the areas change from cut to fill, it is customary to consider the zero of a cut to be the station of no cut immediately preceding or following the station where a cut occurs. The zero of a fill is obtained in a similar manner.

Example. The end areas cut and fill at several stations are as follows:

Sta.	Area Cut	Area Fill
1 + 50	15	0
2	0	22
2 + 50	0	15
3	5	10
3 + 50	20	0
4	25	0
4 + 50	30	0
5	0	12

Sta. 2 is the end of one cut, Sta. 2 + 50 and 5 the beginning and end of another cut. Sta. 1 + 50 and 3 + 50 are the beginning and end of one fill, Sta. 4 + 50 the beginning of another fill.

Earth Shrinkage. It is necessary to make the estimate so that the amount of cut will be in excess of the amount of fill by an amount equal to the shrinkage of the material or it will be necessary to borrow material in the course of the construction to make the embankments. The amount of shrinkage varies depending upon the kind of material, the method of

Table X.—Prismoidal Corrections in Cubic

$c_1 - c_2 =$	1	2	3	4	5	6	7	8	9
$D_1 - D_2$									
0.1	0.03	0.06	0.09	0.12	0.15	0.19	0.22	0.25	0.28
0.2	0.06	0.12	0.19	0.25	0.31	0.37	0.43	0.49	0.56
0.3	0.09	0.19	0.28	0.37	0.46	0.56	0.65	0.74	0.83
0.4	0.12	0.25	0.37	0.49	0.62	0.74	0.86	0.99	1.11
0.5	0.15	0.31	0.46	0.62	0.77	0.93	1.08	1.23	1.39
0.6	0.19	0.37	0.56	0.74	0.93	1.11	1.30	1.48	1.67
0.7	0.22	0.43	0.65	0.86	1.08	1.30	1.51	1.73	1.94
0.8	0.25	0.49	0.74	0.99	1.23	1.48	1.73	1.98	2.22
0.9	0.28	0.56	0.83	1.11	1.39	1.67	1.94	2.22	2.50
1.0	0.31	0.62	0.93	1.23	1.54	1.85	2.16	2.47	2.78
1.1	0.34	0.68	1.02	1.36	1.70	2.04	2.38	2.72	3.06
1.2	0.37	0.74	1.11	1.48	1.85	2.22	2.59	2.96	3.33
1.3	0.40	0.80	1.20	1.60	2.01	2.41	2.81	3.21	3.61
1.4	0.43	0.86	1.30	1.73	2.16	2.59	3.02	3.46	3.89
1.5	0.46	0.93	1.39	1.85	2.31	2.78	3.24	3.70	4.17
1.6	0.49	0.99	1.48	1.98	2.47	2.96	3.46	3.95	4.44
1.7	0.52	1.05	1.57	2.10	2.62	3.15	3.67	4.20	4.72
1.8	0.56	1.11	1.67	2.22	2.78	3.33	3.89	4.44	5.00
1.9	0.59	1.17	1.76	2.35	2.93	3.52	4.10	4.69	5.28
2.0	0.62	1.23	1.85	2.47	3.09	3.70	4.32	4.94	5.56
2.1	0.65	1.30	1.94	2.59	3.24	3.89	4.54	5.19	5.83
2.2	0.68	1.36	2.04	2.72	3.40	4.07	4.75	5.43	6.11
2.3	0.71	1.42	2.13	2.84	3.55	4.26	4.97	5.68	6.39
2.4	0.74	1.48	2.22	2.96	3.70	4.44	5.19	5.93	6.67
2.5	0.77	1.54	2.31	3.09	3.86	4.63	5.40	6.17	6.94
2.6	0.80	1.60	2.41	3.21	4.01	4.81	5.62	6.42	7.22
2.7	0.83	1.67	2.50	3.33	4.17	5.00	5.83	6.67	7.50
2.8	0.86	1.73	2.59	3.46	4.32	5.19	6.05	6.91	7.78
2.9	0.90	1.79	2.69	3.58	4.48	5.37	6.27	7.16	8.06
3.0	0.93	1.85	2.78	3.70	4.63	5.56	6.48	7.41	8.33
3.1	0.96	1.91	2.87	3.83	4.78	5.74	6.70	7.65	8.61
3.2	0.99	1.98	2.96	3.95	4.94	5.93	6.91	7.90	8.89
3.3	1.02	2.04	3.06	4.07	5.09	6.11	7.13	8.15	9.17
3.4	1.05	2.10	3.15	4.20	5.25	6.30	7.35	8.40	9.44
3.5	1.08	2.16	3.24	4.32	5.40	6.48	7.56	8.64	9.72
3.6	1.11	2.22	3.33	4.44	5.56	6.67	7.78	8.89	10.00
3.7	1.14	2.28	3.43	4.57	5.71	6.85	7.99	9.14	10.28
3.8	1.17	2.35	3.52	4.69	5.86	7.04	8.21	9.38	10.56
3.9	1.20	2.41	3.61	4.81	6.02	7.22	8.43	9.63	10.83
4.0	1.23	2.47	3.70	4.94	6.17	7.41	8.64	9.88	11.11
4.1	1.27	2.53	3.80	5.06	6.33	7.59	8.86	10.12	11.39
4.2	1.30	2.59	3.89	5.19	6.48	7.78	9.07	10.37	11.67
4.3	1.33	2.65	3.98	5.31	6.64	7.96	9.29	10.62	11.94
4.4	1.36	2.72	4.07	5.43	6.79	8.15	9.51	10.86	12.22
4.5	1.39	2.78	4.17	5.56	6.94	8.33	9.72	11.11	12.50
4.6	1.42	2.84	4.26	5.68	7.10	8.52	9.94	11.36	12.78
4.7	1.45	2.90	4.35	5.80	7.25	8.70	10.15	11.60	13.06
4.8	1.48	2.96	4.44	5.93	7.41	8.89	10.37	11.85	13.33
4.9	1.51	3.02	4.54	6.05	7.56	9.07	10.59	12.10	13.61
5.0	1.54	3.09	4.63	6.17	7.72	9.26	10.80	12.35	13.89
$c_1 - c_2 =$	1	2	3	4	5	6	7	8	9

Yards for a Solidity 100 Feet Long (3)

$c_1 - c_2 =$	1	2	3	4	5	6	7	8	9
$D_1 - D_2$									
5.1	1.57	3.15	4.72	6.30	7.87	9.44	11.02	12.59	14.17
5.2	1.60	3.21	4.81	6.42	8.02	9.63	11.23	12.84	14.44
5.3	1.64	3.27	4.91	6.54	8.18	9.81	11.45	13.09	14.72
5.4	1.67	3.33	5.00	6.67	8.33	10.00	11.67	13.33	15.00
5.5	1.70	3.40	5.09	6.79	8.49	10.19	11.88	13.58	15.28
5.6	1.73	3.46	5.19	6.91	8.64	10.37	12.10	13.83	15.56
5.7	1.76	3.52	5.28	7.04	8.80	10.56	12.31	14.07	15.83
5.8	1.79	3.58	5.37	7.16	8.95	10.74	12.53	14.32	16.11
5.9	1.82	3.64	5.46	7.28	9.10	10.93	12.75	14.57	16.39
6.0	1.85	3.70	5.56	7.41	9.26	11.11	12.96	14.81	16.67
6.1	1.88	3.77	5.65	7.53	9.41	11.30	13.18	15.06	16.94
6.2	1.91	3.83	5.74	7.65	9.57	11.48	13.40	15.31	17.22
6.3	1.94	3.89	5.83	7.78	9.72	11.67	13.61	15.56	17.50
6.4	1.98	3.95	5.93	7.90	9.88	11.85	13.83	15.80	17.78
6.5	2.01	4.01	6.02	8.02	10.03	12.04	14.04	16.05	18.06
6.6	2.04	4.07	6.11	8.15	10.19	12.22	14.26	16.30	18.33
6.7	2.07	4.14	6.20	8.27	10.34	12.41	14.48	16.54	18.61
6.8	2.10	4.20	6.30	8.40	10.49	12.59	14.69	16.79	18.89
6.9	2.13	4.26	6.39	8.52	10.65	12.78	14.91	17.04	19.17
7.0	2.16	4.32	6.48	8.64	10.80	12.96	15.12	17.28	19.44
7.1	2.19	4.38	6.57	8.77	10.96	13.15	15.34	17.53	19.72
7.2	2.22	4.44	6.67	8.89	11.11	13.33	15.56	17.78	20.00
7.3	2.25	4.51	6.76	9.01	11.27	13.52	15.77	18.02	20.28
7.4	2.28	4.57	6.85	9.14	11.42	13.70	15.99	18.27	20.56
7.5	2.31	4.63	6.94	9.26	11.57	13.89	16.20	18.52	20.83
7.6	2.35	4.69	7.04	9.38	11.73	14.07	16.42	18.77	21.11
7.7	2.38	4.75	7.13	9.51	11.88	14.26	16.64	19.01	21.39
7.8	2.41	4.81	7.22	9.63	12.04	14.44	16.85	19.26	21.67
7.9	2.44	4.88	7.31	9.75	12.19	14.63	17.07	19.51	21.94
8.0	2.47	4.94	7.41	9.88	12.35	14.81	17.28	19.75	22.22
8.1	2.50	5.00	7.50	10.00	12.50	15.00	17.50	20.00	22.50
8.2	2.53	5.06	7.59	10.12	12.65	15.19	17.72	20.25	22.78
8.3	2.56	5.12	7.69	10.25	12.81	15.37	17.93	20.49	23.06
8.4	2.59	5.19	7.78	10.37	12.96	15.56	18.15	20.74	23.33
8.5	2.62	5.25	7.87	10.49	13.12	15.74	18.36	20.99	23.61
8.6	2.65	5.31	7.96	10.62	13.27	15.93	18.58	21.23	23.89
8.7	2.69	5.37	8.06	10.74	13.43	16.11	18.80	21.48	24.17
8.8	2.72	5.43	8.15	10.86	13.58	16.30	19.01	21.73	24.44
8.9	2.75	5.49	8.24	10.99	13.73	16.48	19.23	21.97	24.72
9.0	2.78	5.56	8.33	11.11	13.89	16.67	19.44	22.22	25.00
9.1	2.81	5.62	8.43	11.23	14.04	16.85	19.66	22.47	25.28
9.2	2.84	5.68	8.52	11.36	14.20	17.04	19.88	22.72	25.56
9.3	2.87	5.74	8.61	11.48	14.35	17.22	20.09	22.96	25.83
9.4	2.90	5.80	8.70	11.60	14.51	17.41	20.31	23.21	26.11
9.5	2.93	5.86	8.80	11.73	14.66	17.59	20.52	23.46	26.39
9.6	2.96	5.93	8.89	11.85	14.81	17.78	20.74	23.70	26.67
9.7	2.99	5.99	8.98	11.98	14.97	17.96	20.96	23.95	26.94
9.8	3.02	6.05	9.07	12.10	15.12	18.15	21.17	24.20	27.22
9.9	3.06	6.11	9.17	12.22	15.28	18.33	21.39	24.44	27.50
10.0	3.09	6.17	9.26	12.35	15.43	18.52	21.60	24.69	27.78
$c_1 - c_2 =$	1	2	3	4	5	6	7	8	9

compaction, the weather conditions and the way the material is handled. See Sect. 8 GRADING.

Volumes on Curves. The formulas for computing volumes of earthwork previously given are derived on the assumption that the end areas are parallel to each other. The cross-sections, from which the areas are obtained, on curves are measured in the field on radial lines and hence are not parallel. The volumes obtained by using the formulas previously described will be slightly erroneous. Unless the earthwork on curves consists of very deep cuts and fills as are common to railroad work, the methods of estimating earthwork previously described are generally used without correction. See (1).

The exact volume of a solid on a curve is best found by multiplying the mean area of the solid by the length of the path of its center of gravity. This rule holds true for any solid on a curve that can be generated by a revolving plane area lying wholly on the same side of a straight line.

Example. A simple case of the above is shown in Fig. 59. The solid of uniform shape shown in the figure may be generated by revolving the area *b c d e* about *o*, the center of the curve. The center of gravity of the area is *f*. Area *b c d e* times *a f* the length of the path of *f* gives the volume. The length *a f* is found from angle *a* and radius *o f*.

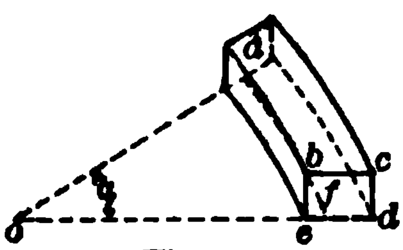

Fig. 59

A Complete Estimate, besides the amount of earthwork, will include the quantities of all the work to be done, such as amounts of guard rail, concrete, ledge, curbing, culvert pipe, drain tile, catch-basins, grubbing and clearing, riprap, foundation material, bituminous material, surfacing material, etc.

Quantities of materials other than earthwork quantities are easily found since the area of cross-section usually corresponds to some regular geometrical figure, the area of which is readily computed by formula. The area in square feet multiplied by the lengths in feet divided by 27 gives cubic yards.

Units of Measurement used in stating the quantities in the estimate vary. Some of the units used are given as follows: Earthwork and ledge, cubic yards; crushed stone, cubic yards, square yards, tons in place, tons loose; foundation materials such as telford, gravel or stone V-drain, square yards and cubic yards; cement-concrete surfacing and concrete foundation, square yards and cubic yards; sheet-asphalt, brick, wood block and similar pavement, square yards; curbing, guard rail, linear feet and size; pipe, linear feet and size; grubbing and clearing, acre, square yard; bituminous material, gross ton, ton pure bitumen, gallon, square yard.

Estimates of Cost are simplified by the use of tables covering costs and quantities for a number of units. Table XI gives the costs per mile of different widths of roadway for unit costs per square yard varying from 10 to 95 cents. Table XII (13) gives square yards and number of gallons required for 1 mile of roadway for various widths and various quantities per square yard.

The Computations are very much simplified and facilitated by using blank forms on which the estimates can be tabulated. Books of standard details of construction giving cross-sections and quantities per linear foot for different types of construction, construction of culverts, catch basins, curbs, guard rails, inlets, and so on with the quantities of material used, are made up usually in blue-print form in every large office. Standard details are used thruout the work wherever possible and the quantities

Table XI.—Cost per Mile of Roadway of Different Widths

Width in Feet	Sq Yd per Mile	Cost per Mile for Different Unit Costs per Sq Yd					
		10 Cents	15 Cents	20 Cents	25 Cents	30 Cents	35 Cents
8	4 693	$469.33	$704.00	$938.66	$1 173.33	$1 408.00	$1 642.67
10	5 867	586.67	880.00	1 173.34	1 466.67	1 760.00	2 053.33
12	7 040	704.00	1 056.00	1 408.00	1 760.00	2 112.00	2 464.00
14	8 213	821.33	1 232.00	1 642.66	2 053.33	2 464.00	2 874.67
16	9 387	938.67	1 408.00	1 877.34	2 346.67	2 816.00	3 285.33
18	10 560	1 056.00	1 584.00	2 112.00	2 640.00	3 168.00	3 696.00
		40 Cents	45 Cents	50 Cents	55 Cents	60 Cents	65 Cents
8	4 693	$1 877.33	$2 112.00	$2 346.67	$2 581.33	$2 816.00	$3 050.67
10	5 867	2 346.67	2 640.00	2 933.33	3 226.67	3 520.00	3 813.33
12	7 040	2 816.00	3 168.00	3 520.00	3 872.00	4 224.00	4 576.00
14	8 213	3 285.33	3 696.00	4 106.67	4 517.33	4 928.00	5 338.67
16	9 387	3 754.67	4 224.00	4 693.33	5 162.67	5 632.00	6 101.33
18	10 560	4 224.00	4 752.00	5 280.00	5 808.00	6 336.00	6 864.00
		70 Cents	75 Cents	80 Cents	85 Cents	90 Cents	95 Cents
8	4 693	$3 285.33	$3 520.00	$3 754.67	$3 989.33	$4 224.00	$4 458.67
10	5 867	4 106.67	4 400.00	4 693.33	4 986.67	5 280.00	5 573.33
12	7 040	4 928.00	5 280.00	5 632.00	5 984.00	6 336.00	6 688.00
14	8 213	5 749.33	6 160.00	6 570.67	6 981.33	7 392.00	7 802.67
16	9 387	6 570.67	7 040.00	7 509.33	7 978.67	8 448.00	8 917.33
18	10 560	7 392.00	7 920.00	8 448.00	8 976.00	9 504.00	10 032.00

Table XII.—Gallons Required per Mile of Roadway of Different Widths

Width of Roadway	Square Yards	Quantities per Square Yard	Gallons
10 ft	5 866	¼ gal	1 467
10 ft	5 866	½ gal	2 933
10 ft	5 866	1 gal	5 867
10 ft	5 866	1½ gal	8 800
12 ft	7 040	¼ gal	1 760
12 ft	7 040	½ gal	3 520
12 ft	7 040	1 gal	7 040
12 ft	7 040	1½ gal	10 560
14 ft	8 213	¼ gal	2 053
14 ft	8 213	½ gal	4 107
14 ft	8 213	1 gal	8 213
14 ft	8 213	1½ gal	12 320
16 ft	9 386	¼ gal	2 347
16 ft	9 386	½ gal	4 693
16 ft	9 386	1 gal	9 387
16 ft	9 386	1½ gal	14 080
18 ft	10 560	¼ gal	2 640
18 ft	10 560	½ gal	5 280
18 ft	10 560	1 gal	10 560
18 ft	10 560	1½ gal	15 840

involved are obtained from the book of standards with but very little computation. A book of standard details also saves much time in the office that would otherwise be spent in making sketches. Each inspector or resident engineer is supplied with this book and can refer to it for information regarding the construction of any standard detail.

31. Overhaul and Mass Diagram

Overhaul. In many specifications is a clause stating the distance that excavated material, taken either from along the location of the work or from outside the location, shall be hauled without extra charge. This distance is called the free haul and is usually 1000 to 2000 ft. Material hauled a greater distance than the free haul is paid for at so much a cubic yard, usually ½ to 1 cent for each 100 ft of distance in excess of the free haul. The distance in excess of the free haul is called overhaul. The overhaul on material taken from outside the location or borrow is usually calculated by measuring the distance from the borrow pit to the nearest point of the highway to be built and subtracting the free haul. The overhaul on excavated material taken from the highway location to a dump is calculated in a similar manner from the distance between the dump and the nearest point of the highway. Some specifications make no provision for overhaul at all.

Mass Diagram. In order to study an estimate and see where it is economical to borrow or waste excavated material, a mass diagram should be constructed. The cubic yards of cut and fill are calculated for each interval between the regular stations from the beginning to the end of the work. Where a cut and a fill occur in the same interval, the algebraic sum is taken as the volume of the interval, considering cut to be plus and the fill to be minus. Where the volume in an interval is either all cut or all fill, it is noted down with a plus or minus sign before it. Starting with the first station, the total volumes are found up to each station by adding successively the volumes for each interval up to and including the station in question, taking into account the plus or minus sign. The total volumes are plotted vertically from a base line *a a* (see Fig. 60), on which the stations have been scaled off horizontally in a similar manner to the way a profile is plotted. See (1).

Example. The stations and volumes and total volumes for a simple case are as follows:

Station.................	0	1	2	3	4	5
Volume.................	0	+70	+180	+100	−400	−100
Total Volume..........	0	+70	+250	+350	−50	−150

The total volume for Sta. 1 is algebraic sum of volumes for Sta. 0 and 1

The total volume for Sta. 2 is algebraic sum of volumes for Sta. 0, 1 and 2

The total volume for Sta. 5 is algebraic sum of volumes for Sta. 0, 1, 2, 3, 4, and 5.

A mass diagram has several properties which follow from its method of construction. Fig. 60 shows a diagram constructed with reference to *a a* as a base line. Ascending lines represent cuts and descending lines fills. The high and low points *b* in the diagram are points where the grade changes from cut to fill or vice versa. The difference in length between any two adjacent vertical ordinates is the volume of material between these two stations. A horizontal line *c d* or *e e* drawn at any point in the diagram

Fig. 60

shows that cut and fill between the stations, corresponding to the perpendiculars from the ends of the line, just balance. If the area between the curved line of the diagram and the horizontal line is above the horizontal line, it indicates that the cut is to be moved forward to make the fill, if below, the cut is to be moved backward. The total solidity between any two stations corresponding to *c* and *d* is the value of the maximum ordinate *e b* at *b* measured between the line *c d* and *b*. The average haul for a total solidity above a horizontal line *c d* is the area *c d b* between *c d* and the curved line of the diagram divided by the total solidity *e b*, or the average haul is the horizontal distance between the centers of gravity of equivalent volumes of cut and fill.

To show how the diagram is used, it is necessary to state how free haul and overhaul are considered with reference to material moved within the limits of the highway location. The interpretation of these two terms by the Am. Ry. Engrs. and Maintenance of Way Assn. is briefly stated as follows: Free haul is determined by fixing two points on the profile either side of the neutral grade point such that the distance between them equals the specified free haul limit and the included quantities of excavation and embankment balance. Material within the free haul limit need not be considered further. The distance between the center of gravity of the remaining mass of excavation and center of gravity of the resulting embankment less the limit of free haul is the length of overhaul. If the free haul limit is assumed to be 1000 ft, draw lines on the mass diagram in Fig. 60 corresponding to line *c d* which is just 1000 ft long. Project the verticals from *c* and *d* to the profile. The cut and fill between the two stations corresponding to these verticals just balance. In this particular diagram the remainder of the mass *r a d* just balances *r a c* but there is some overhaul in moving *r a d* to *r a c*. The overhaul is the distance between the centers of gravity of these two masses minus 1000 ft. The stations of the centers of gravity of the areas *r a d* and *r a c* of the diagram can be computed and the amount of overhaul determined. The cost of a cubic yard of excavation plus the cost of overhaul should be compared with the cost of wasting the volume *r d* and borrowing the volume *r c*.

Example. Suppose the cost of overhaul is 2 cents per cu yd, the limit of free haul 1000 ft and the overhaul calculated as described is 4000 ft and the cost of excavation is 25 cents per cu yd. The cost then of moving a cubic yard of earth from the volume *r a d* to *r a c* is $25 + 2 \times 40 = \$1.05$. Suppose borrow can be obtained for 35 cents a cu yd. If excavation *r a d* is wasted and *r a c* is borrowed, the cost per cu yd is $25 + 35 = 60$ cents or a saving of 45 cents per cu yd. Suppose the total solidity as scaled from *r d* is 600 cu yds, then the saving accomplished by wasting the excavation and borrowing material is 600×45 cents $= \$270$.

This illustration is a simple one but shows in a general way how the diagram may be used. In highway work the prices for excavation and borrow are generally higher than prices for the same items in railroad work and the cost of overhaul is low. Hence the overhauls have to be of considerable length before much saving is effected in wasting and borrowing.

GENERAL DATA

32. Cost of Surveying and Mapping

The Average Cost per mile for surveying, plotting, estimating, and staking road surveys may be taken as follows: Surveying, \$40; plotting and checking, \$15; estimating, \$15; tracing, \$5; staking, \$20; total, \$95.

The above costs are figured on the basis that a party of 4 men will complete a 1-mile survey in 2 days unless the line requires a great many curves and the number of houses or other objects to be located is large, in which case the cost would be increased. Board of the men is included, but not transportation. The plotting and checking include cost of material, and is figured on the basis of men receiving $4 per day. Estimating includes the work of establishing the grade line and its examination in the field. The cost of staking is figured on the basis that a party of 4 men will stake 1 mile in 1 day and includes cost of board, but not transportation.

The average cost per mile of surveying and plotting state roads in Pennsylvania preliminary to construction from June 1911 to Jan. 1913 was as follows: Survey, $47.40; plotting, $11.44; checking and tracing, $8.44: total cost per mile, $67.28.

The Cost of Precise Leveling as carried out by the U. S. Coast and Geodetic Survey averages about $11 per mile and ranges from about $7 to $17 per mile.

These figures include the establishment of bench-marks, transportation to and from field of the men and cost of computations, but do not include cost of instruments and stationery. The party was usually made up of 5 men: 1 observer, 2 rodmen, 1 to hold sunshade and 1 to hold wind shield. The average speed of the work varies from about 100 to 150 miles per month.

The Cost of Measuring Four Base Lines by the U. S. Coast and Geodetic Survey in connection with the primary triangulation on the 109th meridian and the 39th parallel in Colorado, Utah and Nevada varied from $85 to $134 per mile, an average cost being $116 per mile. The above cost includes the cost of standardizing tapes, traveling expenses and computations. The average speed of the work was about 1 mile per hour.

The Cost of Primary Triangulation work as carried on by the U. S. Coast and Geodetic Survey is shown in Table XIII for three different surveys.

Table XIII.—Cost of Primary Triangulation

Name of Arc	Months of Observation	Primary Stations Occupied	Stations Occupied per Month	Total Field Expenses	Cost per Station Occupied	Total Points Determined	Cost per Point Determined	Miles of Progress	Cost per Mile of Progress	Area in Main Scheme Sq M	Cost per Sq Mile
104th Meridian	13.7	82	6.0	$28850	$352	167	$173	720	$40	17000	$1.70
98th Meridian	39.8	265	6.7	78187	293	849	109	1829	63	21655	5.19
Texas-Califor'a.	16.7	94	5.6	38384	408	262	147	1207	32	49220	0.78

Remarks: The total expenses include the cost of preparing and marking the stations but not the cost of reconnaissance.

The Costs of Topographical Surveys (29) for large areas and railroad preliminaries are given in Tables XIV and XV. The following notes should be used in connection with Table XIV.

1. On 95% of the area, points were established on 5-ft contours with a wye level and located with a plane-table. Remaining 5% was wooded and points on 5-ft contours were established by and located with a stadia traverse. Land hilly with rise of 120 ft.

2. On 40% of the area, points were established on 2.5-ft contours and on another 40% on 5-ft contours with wye level and located with plane-table. Remaining 20% was wooded and points on 5-ft contours were established and located with stadia traverse. Land hilly with rise of 180 ft.

3. On 70% of the area, points were established on 5-ft contours with wye level and located with a plane-table. Remaining 30% was wooded and points on 5-ft contours were established and located with stadia traverse. Land rolling with rise of 80 ft.

4. On 40% of the area, points were established on 3-ft contours and on 30% on 6-ft contours with wye level and located with a plane-table. Remaining 30% was wooded and elevations were obtained by stadia and contours interpolated. Extra large number of buildings and railroads were located. Land rough and mountainous with rise of 430 ft.

5. Points established on 5-ft contours by wye level and located with plane-table. Land rolling with rise of 60 ft.

6. On 90% of the area, points were established on 10-ft contours with wye level and located with a plane-table. Remaining 10% was wooded and points on 10-ft contours were established and located with stadia traverse. All roads were traversed and chained. Land hilly with a rise of 150 ft.

7. Survey made entirely with stadia. Tape not used. Streams, ridges and two coal outcrop lines traversed and topography taken by stadia and vertical angles. Contours interpolated. Levels on transit lines carried along by stadia and vertical angles. Stadia lines tied on to outline survey made previously. Land rough and mountainous with a rise of 1150 ft. 259 miles of stadia work cost $14.68 per mile.

Table XIV.—Cost of Topographic Surveys for Large Areas

Number	Location	Size Acres	Hr per Day	Time: Field	Time: 1 Man in Office	Cost: Field	Cost: Office	Total Cost	Cost per Acre	Map Scale	Survey Made
1	Penn.	308	6½	40 days 3 men	10 days	$327	$45	$372	$1.20	1″ = 100′	Aug to Oct
2	Penn.	190	7	22 days 3 men	9 days	194	38	232	1.22	1″ = 60′	Dec to Jan
3	Penn.	104	7½	8 days 3 men	1 day	74	4	78	0.75	1″ = 100′	June
4	Penn.	300	8	40 days 3 men	22 days	480	92	572	1.90	1″ = 100′	Nov to Dec
5	Penn.	99	7½	12 days 3 men	4½ days	115	23	138	1.20	1″ = 100′	Feb to Mar
6	Penn.	1464	8½	87 days 3 men	18 days	1052	92	1144	0.78	1″ = 200′	Sept to Dec
7	W. Va.	11264	8	222 days 4 men	65 days	3791	386	4177	0.37	1″ = 500′	Oct to Feb

Remarks: Field cost includes transportation and subsistence in Nos. 4 and 7.

Table XV.—Cost of Topographic Surveys for Railroads

Number	Location	Length Miles	Hr per Day	Time: Field	Time: 1 Man in Office	Cost: Field	Cost: Office	Total Cost	Cost per Mile	Map Scale	Survey Made
1	N. C.	26	8½	74 days 4 men	24 days	$1450	$144	$1594	$61.30	1″ = 200′	June to Aug
2	Va.	27.5	8½	75 days 4 men	25 days	1400	150	1550	56.40	1″ = 200′	Aug to Nov
3	Penn.	12	8½	50 days 4 men	35 days	1011	165	1176	98.00	1″ = 200′	Feb to Mar
4	Penn.	5.1	8½	14 days 4 men	14 days	236	43	279	54.60	1″ = 200′	May to June
5	Cuba	34	8	43 days 9 men	54 days	848	238	1086	32.00	1″ = 200′	Nov to Jan

Remarks: Field cost includes transportation and subsistence except in case of No. 5. In all cases the transit line was chained except in No. 5 where part of the line was measured with stadia. The topography in Nos. 1 and 2 was taken with a Y level and cross sections; in Nos. 3 and 4 with stadia and plane-table; in No. 5 with Y level and stadia. Character of country: No. 1, hilly and wooded; No. 2, 50% woods and mountains, 50% open; No. 3, rolling and open, extra large number of locations, towns, railroads, etc; No. 4, rolling and open, large number of extra locations; No. 5 mountainous and heavily wooded, cost of reconnaissance increased as no maps of country were at hand. The above costs in all cases include making a preliminary estimate.

33. Indexing, Filing and Recording

There is considerable variation in the methods used in different offices in indexing and filing drawings, note books and other information incidental to the work.

Filing Drawings. Drawings are filed flat or in rolls. When filed flat they are usually put in drawers. Cases of drawers are manufactured in various sizes for this purpose. Drawings filed in this way are prepared on standard size sheets and in some offices the size of the standard sheet is never exceeded so that there is never any need of folding a drawing. Some title or number should appear in the lower right hand corner of the drawing so that it may be found by turning up the right hand corners of the sheets in the drawer. If there are several different sizes of standard drawings, it is advisable to have corresponding different sizes of drawers to accommodate them. See (5).

There are so many different ways of filing drawings that only one method will be suggested. Each drawing should have a number. If they are entirely different in character, they should also be given a distinctive class letter. A card should be attached to the drawer that they are filed in bearing the class letter and the range of numbers of the drawings in the drawer.

Long drawings cannot readily be filed flat and it is more customary to roll them and sometimes put them in pasteboard or metal tubes. The rolls are placed in racks. Where drawings are filed in this manner, each end of the drawing should bear an appropriate title or number so that no matter how the drawing is rolled up, its distinctive mark may be read at the end. The racks are given the same marks as the drawings which they contain in a similar manner to marking the drawers as described above.

Indexing Drawings. The best and most flexible method of indexing drawings is by the card index system. The index cards can be arranged in alphabetical order in the cases of streets, counties or towns or numerically where a system of numbered routes and sections is employed. Separate indexes may be prepared for drawings of different classes, such as sidewalks, streets, cross-sections, bridges, etc. Each card should contain a brief description of the drawing, stating whether it is a tracing, blue-print, detail or general drawing; in fact, giving enough information so that the drawing desired may be found from the index. The card should obviously be marked with the same distinctive mark as the drawing. See (5).

Filing and Indexing Notebooks. Notebooks should be preserved with great care. In fact in some offices they are filed in safes or fire-proof vaults. They are very valuable, and in event of their loss it would not only be a matter of great expense to replace them, but the difficulty and confusion that would arise would be of even far greater importance. In highway work it is very convenient not to have more than one survey in a book. If a book is taken from the office into the field, then only one survey is out, and if the book should be lost or destroyed only one survey is affected.

Having more than one survey in a notebook will frequently hinder the field or office work in cases where the notes of two or more of the surveys in the book are wanted at the same time by different persons. Each notebook should be given a distinctive title or number, usually placed on the back of the book so as to be readily seen. What has been previously said relative to marking and indexing drawings applies as well to notebooks. A card index is the best form of index to use. See (5).

Filing and Indexing Computations. Many of the routine office computations can be tabulated on printed forms. Such forms can be prepared for recording the estimate computations, triangulation and traverse work and so on, so that all the results and important work of the computations is recorded in the same manner. These forms not only save time but are often an aid to the computer in preventing omissions. If the forms are punched they may be filed in loose leaf notebooks and later be removed and placed in filing cases which can be obtained in almost any size or style desired. A card index should be prepared for each different kind of printed form that is used. See (5).

Recording Progress of Work is very essential to the smooth working of the engineering force where any great amount of work is in the process of planning or construction. The fundamental idea in recording is to present the status of the particular part of the work in question so that it can be quickly and easily interpreted without looking over a mass of detailed data. See (5). See also Sec. 29.

Town of
Notes
Traverse chk'd, Profile chk'd
Rail chk'd, Cross Sections chk'd
Drawing Approved by Board
Profile chk'd Inked
Verticals and Base chk'd Inked
Rail, Old Location chk'd Inked
Rail, New Location chk'd Inked
Plan
Traverse Inked
Topography Inked
Travelled Way Inked
Center Line of Finished Road Inked
Title Inked
Road Section Inked
Grade chk'd F. B. Engr. B. Inked
Grade chk'd F. B. Engr. B. Inked
Grade chk'd F. B. Engr. B. Inked
Grade chk'd F. B. Engr. B. Inked
Cross Sections Approved by Board
Cross Sections chk'd Inked
Sub Sections chk'd Inked
For Grade of chk'd Inked
For Grade of chk'd Inked
For Grade of chk'd Inked
Estimate
For Grade of State State and Town
For Grade of State State and Town
For Grade of State State and Town
Tracing Approved by Board
Plan and Profile
Title
Grade
Road Section
Data
Length Depth
Widths
Road Sections
Center Line

Fig. 61. Office Record

Progress of construction work can be recorded on blue-prints of the plan or profile using different colored crayons, each month's work having a distinctive color. Small progress charts can be made, suitable for filing in a loose leaf notebook, on which the quantities of each class of work such as ledge, concrete, etc, for any particular job is plotted to any arbitrary vertical scale. The monthly progress of each class of work can be marked off on its respective vertical to the same scale, an appropriate designation being made by recording the date or otherwise so that each month's work is readily found. The progress of the construction of finished roads or of surveys of roads on any system of highways can be recorded by taking a plan map of the system and inking in the road lengths as they are built or surveyed, using different colored inks to correspond with certain intervals of time over which the work extended.

Mobile forces such as repair gangs or survey parties can be kept track of as to their location by means of glass headed pins of different colors, stuck in a plan map of the system to correspond with the location of the men.

A form for recording the progress of the office work for each survey is shown in Fig. 61. This form is on an 8½ by 11-in sheet and is punched for filing in a loose leaf notebook. The printed headings cover the different steps of the work necessary in working up the field notes, plotting, estimating and tracing. After each heading a man signs his initials and the date on which he completed that particular step of the work. When the work is checked or inked it is signed for in the same manner after the heading checked or inked. This form shows the condition of the office work for any survey at a glance and tends to increase the efficiency of the office force.

34. General Tables

The tables in this Article will be found convenient in connection with many of the problems arising in field and office work.

Table XVI.—Linear Measure (13)

Inches	Feet	Yards	Rods	Furlongs	Miles
1	0.08333	0.02778	0.0050505	0.00012626	0.00001578
12	1.0	0.33333	0.0606061	0.00151515	0.00018939
36	3.0	1.0	0.1818182	0.00454545	0.00056818
198	16.5	5.5	1.	0.025	0.003125
7920	660.	220.	40.	1.	0.125
63360	5280.	1760.	320.	8.	1.

Table XVII.—Land Measure (13)

Square Inches	Square Feet	Square Yards	Square Rods	Acres	Square Miles
1	0.006944	.0007716	....	....	....
144	1.00	.111111	....	....	....
1296	9.00	1.00	0.03306	0.0002066	....
39204	272.25	30.25	1.	0.00625	0.00000977
6272640	43560.	4840.	160.	1.	0.0015625
	27878400.	3097600.	102400.	640.	1.

Table XVIII.—Cubic or Solid Measure (13)

Cubic Inches	Cubic Feet	Cubic Yards	Cord	Perch
1	.0005787	.000021433	...	...
1728	1.00	.03703704	...	...
46656	27.00	1.000000	...	...
221184	128.00	4.074074	1.0	...
42768	24.75	.916666	...	1.0

1 cord = 4 by 4 by 8 ft.
1 perch of masonry = 16.5 by 1.5 by 1 ft. It is usually taken as 25 cu ft.

Table XIX.—Miles and Tenths Reduced to Feet (13)

Miles.....	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	0.1
Feet......	5280	5808	6336	6864	7392	7924	8446	8976	9504	10032	528
Miles.....	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	0.2
Feet......	10560	11088	11616	12144	12674	13204	13728	14256	14784	15312	1056
Miles.....	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	0.3
Feet......	15840	16386	16896	17424	17952	18484	19008	19536	20064	20592	1584
Miles.....	4.0	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	0.4
Feet......	21120	21648	22176	22704	23232	23764	24288	24816	25344	25872	2112
Miles.....	5.0	5.1	5.2	5.3	5.4	5.5	5.6	5.7	5.8	5.9	0.5
Feet......	26400	26928	27456	27984	28512	29044	29568	30096	30624	31152	2644
Miles.....	6.0	6.1	6.2	6.3	6.4	6.5	6.6	6.7	6.8	6.9	0.6
Feet......	31680	32208	32736	33264	33792	34324	34848	35376	35904	36432	3168
Miles.....	7.0	7.1	7.2	7.3	7.4	7.5	7.6	7.7	7.8	7.9	0.7
Feet......	36960	37488	38016	38544	39072	39600	40128	40656	41184	41712	3696
Miles.....	8.0	8.1	8.2	8.3	8.4	8.5	8.6	8.7	8.8	8.9	0.8
Feet......	42240	42768	43296	43824	44352	44880	45408	45936	46464	46992	4224
Miles.....	9.0	9.1	9.2	9.3	9.4	9.5	9.6	9.7	9.8	9.9	0.9
Feet......	47520	48048	48576	49104	49632	50160	50688	51216	51744	52272	4752

Table XX.—Inches and Fractions Reduced to Decimals of a Foot (37)

Inch	0 In	1 In	2 In	3 In	4 In	5 In	6 In	7 In	8 In	9 In	10 In	11 In
0 ...	0	.0833	.1667	.2500	.3333	.4167	.5000	.5833	.6667	.7500	.8333	.9167
1-64...	.0013	.0846	.1680	.2513	.3346	.4180	.5013	.5846	.6680	.7513	.8346	.9180
1-32...	.0026	.0859	.1693	.2526	.3359	.4193	.5026	.5859	.6693	.7526	.8359	.9193
3-64...	.0039	.0872	.1706	.2539	.3372	.4206	.5039	.5872	.6706	.7539	.8372	.9206
1-16..	.0052	.0885	.1719	.2552	.3385	.4219	.5052	.5885	.6719	.7552	.8385	.9219
5-64...	.0065	.0898	.1732	.2565	.3398	.4232	.5065	.5898	.6732	.7565	.8398	.9232
3-32...	.0078	.0911	.1745	.2578	.3411	.4245	.5078	.5911	.6745	.7578	.8411	.9245
7-64...	.0091	.0924	.1758	.2591	.3424	.4258	.5091	.5924	.6758	.7591	.8424	.9258
1-8....	.0104	.0937	.1771	.2604	.3437	.4271	.5104	.5937	.6771	.7604	.8437	.9271
9-64...	.0117	.0951	.1784	.2617	.3451	.4284	.5117	.5951	.6784	.7617	.8451	.9284
5-32...	.0139	.0964	.1797	.2630	.3464	.4297	.5130	.5964	.6797	.7630	.8464	.9297
11-64...	.0143	.0977	.1810	.2643	.3477	.4310	.5143	.5977	.6810	.7643	.8477	.9310
3-16...	.0156	.0990	.1823	.2656	.3490	.4323	.5156	.5990	.6823	.7656	.8490	.9323
13-64...	.0169	.1003	.1836	.2669	.3503	.4336	.5169	.6003	.6836	.7669	.8503	.9336
7-32...	.0182	.1016	.1849	.2682	.3516	.4349	.5182	.6016	.6849	.7682	.8516	.9349
15-64...	.0195	.1029	.1862	.2695	.3529	.4362	.5195	.6029	.6862	.7695	.8529	.9362
1-4....	.0208	.1042	.1875	.2708	.3542	.4375	.5208	.6042	.6875	.7708	.8542	.9375
17-64...	.0221	.1055	.1888	.2721	.3555	.4388	.5221	.6055	.6888	.7721	.8555	.9388
9-32...	.0234	.1068	.1901	.2734	.3568	.4401	.5234	.6068	.6901	.7734	.8568	.9401
19-64...	.0247	.1081	.1914	.2747	.3581	.4414	.5247	.6081	.6914	.7747	.8581	.9414
5-16...	.0260	.1094	.1927	.2760	.3594	.4427	.5260	.6094	.6927	.7760	.8594	.9427
21-64...	.0273	.1107	.1940	.2773	.3607	.4440	.5273	.6107	.6940	.7773	.8607	.9440
11-32...	.0286	.1120	.1953	.2786	.3620	.4453	.5286	.6120	.6953	.7786	.8620	.9453
23-64...	.0299	.1133	.1966	.2799	.3633	.4466	.5299	.6133	.6966	.7799	.8633	.9466
3-8....	.0312	.1146	.1979	.2812	.3646	.4479	.5312	.6146	.6979	.7812	.8646	.9479

Table XX.— Inches and Fractions Reduced to Decimals of a Foot (37)

Inch	0 In	1 In	2 In	3 In	4 In	5 In	6 In	7 In	8 In	9 In	10 In	11 In
25-64...	.0326	.1159	.1992	.2826	.3659	.4492	.5326	.6159	.6992	.7826	.8659	.9492
13-32...	.0339	.1172	.2005	.2839	.3672	.4505	.5339	.6172	.7005	.7839	.8672	.9505
27-64...	.0352	.1185	.2018	.2852	.3685	.4518	.5352	.6185	.7018	.7852	.8685	.9518
7-16...	.0365	.1198	.2031	.2865	.3698	.4531	.5356	.6198	.7031	.7865	.8698	.9531
29-64...	.0378	.1211	.2044	.2878	.3711	.4544	.5378	.6211	.7044	.7878	.8711	.9544
15-32...	.0391	.1224	.2057	.2891	.3724	.4557	.5391	.6224	.7057	.7891	.8724	.9557
31-64...	.0404	.1237	.2070	.2904	.3737	.4570	.5404	.6237	.7070	.7904	.8737	.9570
1-2....	.0417	.1250	.2083	.2917	.3750	.4583	.5417	.6250	.7083	.7917	.8750	.9583
33-64...	.0430	.1263	.2096	.2930	.3763	.4596	.5430	.6263	.7096	.7930	.8763	.9596
17-32...	.0443	.1276	.2109	.2943	.3776	.4609	.5443	.6276	.7109	.7943	.8776	.9609
35-64...	.0456	.1289	.2122	.2956	.3789	.4622	.5456	.6289	.7122	.7956	.8789	.9622
9-16...	.0469	.1302	.2135	.2969	.3802	.4635	.5469	.6302	.7135	.7969	.8802	.9635
37-64...	.0482	.1315	.2148	.2982	.3815	.4648	.5482	.6315	.7148	.7982	.8815	.9648
19-32...	.0495	.1328	.2161	.2995	.3828	.4661	.5495	.6328	.7161	.7995	.8828	.9661
39-64...	.0508	.1341	.2174	.3008	.3841	.4674	.5508	.6341	.7174	.8008	.8841	.9674
5-8....	.0521	.1354	.2188	.3021	.3854	.4688	.5521	.6354	.7188	.8021	.8854	.9688
41-64...	.0534	.1367	.2201	.3034	.3867	.4701	.5534	.6367	.7201	.8034	.8867	.9701
21-32...	.0547	.1380	.2214	.3047	.3880	.4714	.5547	.6380	.7214	.8047	.8880	.9714
43-64...	.0560	.1393	.2227	.3060	.3893	.4727	.5560	.6393	.7227	.8060	.8893	.9727
11-16...	.0573	.1406	.2240	.3073	.3906	.4740	.5573	.6406	.7240	.8073	.8906	.9740
45-64...	.0586	.1419	.2253	.3086	.3919	.4753	.5586	.6419	.7253	.8086	.8919	.9753
23-32...	.0599	.1432	.2266	.3099	.3932	.4766	.5599	.6432	.7266	.8099	.8932	.9766
47-64...	.0612	.1445	.2279	.3112	.3945	.4779	.5612	.6445	.7279	.8112	.8945	.9779
3-4....	.0625	.1458	.2292	.3125	.3958	.4792	.5625	.6458	.7292	.8125	.8958	.9792
49-64...	.0638	.1471	.2305	.3138	.3971	.4805	.5638	.6471	.7305	.8138	.8971	.9805
25-32...	.0651	.1484	.2318	.3151	.3984	.4818	.5651	.6484	.7318	.8151	.8984	.9818
51-64...	.0664	.1497	.2331	.3164	.3997	.4831	.5664	.6497	.7331	.8164	.8997	.9831
13-16...	.0677	.1510	.2344	.3177	.4010	.4844	.5677	.6510	.7344	.8177	.9010	.9844
53-64...	.0690	.1523	.2357	.3190	.4023	.4857	.5690	.6523	.7357	.8190	.9023	.9857
27-32...	.0703	.1536	.2370	.3203	.4036	.4870	.5703	.6536	.7370	.8203	.9036	.9870
55-64...	.0716	.1549	.2383	.3216	.4049	.4883	.5716	.6549	.7383	.8216	.9049	.9883
7-8....	.0729	.1562	.2396	.3229	.4062	.4896	.5729	.6562	.7396	.8229	.9062	.9896
57-64...	.0742	.1576	.2409	.3242	.4076	.4909	.5742	.6576	.7409	.8242	.9076	.9909
29-32...	.0755	.1589	.2422	.3255	.4089	.4922	.5755	.6589	.7422	.8255	.9089	.9922
59-64...	.0768	.1602	.2435	.3268	.4102	.4935	.5768	.6602	.7435	.8268	.9102	.9935
15-16...	.0781	.1615	.2448	.3281	.4115	.4948	.5781	.6615	.7448	.8281	.9115	.9948
61-64...	.0794	.1628	.2461	3294	.4128	.4961	.5794	.6628	.7461	.8294	.9128	.9961
31-32...	.0807	.1641	.2474	.3307	.4141	.4974	.5807	.6641	.7474	.8307	.9141	.9974
63-64...	.0820	.1654	.2487	.3320	.4154	.4987	.5820	.6654	.7487	.8320	.9154	.9987

Table XXI.—Natural Sines and Cosines (10b)

SINE

Angle	0′	10′	20′	30′	40′	50′	60′	
0°	0.00000	0.00291	0.00582	0.00873	0.01164	0.01454	0.01745	89
1	0.01745	0.02036	0.02327	0.02618	0.02908	0.03199	0.03490	88
2	0.03490	0.03781	0.04071	0.04362	0.04653	0.04943	0.05234	87
3	0.05234	0.05524	0.05814	0.06105	0.06395	0.06685	0.06976	86
4	0.06976	0.07266	0.07556	0.07846	0.08136	0.08426	0.08716	85°
5°	0.08716	0.09005	0.09295	0.09585	0.09874	0.10164	0.10453	84
6	0.10453	0.10742	0.11031	0.11320	0.11609	0.11898	0.12187	83
7	0.12187	0.12476	0.12764	0.13053	0.13341	0.13629	0.13917	82
8	0.13917	0.14205	0.14493	0.14781	0.15069	0.15356	0.15643	81
9	0.15643	0.15931	0.16218	0.16505	0.16792	0.17078	0.17365	80°
10°	0.17365	0.17651	0.17937	0.18224	0.18509	0.18795	0.19081	79
11	0.19081	0.19366	0.19652	0.19937	0.20222	0.20507	0.20791	78
12	0.20791	0.21076	0.21360	0.21644	0.21928	0.22212	0.22495	77
13	0.22495	0.22778	0.23062	0.23345	0.23627	0.23910	0.24192	76
14	0.24192	0.24474	0.24756	0.25038	0.25320	0.25601	0.25882	75°
15°	0.25882	0.26163	0.26443	0.26724	0.27004	0.27284	0.27564	74
16	0.27564	0.27843	0.28123	0.28402	0.28680	0.28959	0.29237	73
17	0.29237	0.29515	0.29793	0.30071	0.30348	0.30625	0.30902	72
18	0.30902	0.31178	0.31454	0.31730	0.32006	0.32282	0.32557	71
19	0.32557	0.32832	0.33106	0.33381	0.33655	0.33929	0.34202	70°
20°	0.34202	0.34475	0.34748	0.35021	0.35293	0.35565	0.35837	69
21	0.35837	0.36108	0.36379	0.36650	0.36921	0.37191	0.37461	68
22	0.37461	0.37730	0.37999	0.38268	0.38537	0.38805	0.39073	67
23	0.39073	0.39341	0.39608	0.39875	0.40142	0.40408	0.40674	66
24	0.40674	0.40939	0.41204	0.41469	0.41734	0.41998	0.42262	65°
25°	0.42262	0.42525	0.42788	0.43051	0.43313	0.43575	0.43837	64
26	0.43837	0.44098	0.44359	0.44620	0.44880	0.45140	0.45399	63
27	0.45399	0.45658	0.45917	0.46175	0.46433	0.46690	0.46947	62
28	0.46947	0.47204	0.47460	0.47716	0.47971	0.48226	0.48481	61
29	0.48481	0.48735	0.48989	0.49242	0.49495	0.49748	0.50000	60°
30°	0.50000	0.50252	0.50503	0.50754	0.51004	0.51254	0.51504	59
31	0.51504	0.51753	0.52002	0.52250	0.52498	0.52745	0.52992	58
32	0.52992	0.53238	0.53484	0.53730	0.53975	0.54220	0.54464	57
33	0.54464	0.54708	0.54951	0.55194	0.55436	0.55678	0.55919	56
34	0.55919	0.56160	0.56401	0.56641	0.56880	0.57119	0.57358	55°
35°	0.57358	0.57596	0.57833	0.58070	0.58307	0.58543	0.58779	54
36	0.58779	0.59014	0.59248	0.59482	0.59716	0.59949	0.60182	53
37	0.60182	0.60414	0.60645	0.60876	0.61107	0.61337	0.61566	52
38	0.61566	0.61795	0.62024	0.62251	0.62479	0.62706	0.62932	51
39	0.62932	0.63158	0.63383	0.63608	0.63832	0.64056	0.64279	50°
40°	0.64279	0.64501	0.64723	0.64945	0.65166	0.65386	0.65606	49
41	0.65606	0.65825	0.66044	0.66262	0.66480	0.66697	0.66913	48
42	0.66913	0.67129	0.67344	0.67559	0.67773	0.67987	0.68200	47
43	0.68200	0.68412	0.68624	0.68835	0.69046	0.69256	0.69466	46
44	0.69466	0.69675	0.69883	0.70091	0.70298	0.70505	0.70711	45°
	60′	50′	40′	30′	20′	10′	0′	Angle

COSINE

Table XXI.—Natural Sines and Cosines (10b)

SINE

Angle	0′	10′	20′	30′	40′	50′	60′	
45°	0.70711	0.70916	0.71121	0.71325	0.71529	0.71732	0.71934	44
46	0.71934	0.72136	0.72337	0.72537	0.72737	0.72937	0.73135	43
47	0.73135	0.73333	0.73531	0.73728	0.73924	0.74120	0.74314	42
48	0.74314	0.74509	0.74703	0.74896	0.75088	0.75280	0.75471	41
49	0.75471	0.75661	0.75851	0.76041	0.76229	0.76417	0.76604	40°
50°	0.76604	0.76791	0.76977	0.77162	0.77347	0.77531	0.77715	39
51	0.77715	0.77897	0.78079	0.78261	0.78442	0.78622	0.78801	38
52	0.78801	0.78980	0.79158	0.79335	0.79512	0.79688	0.79864	37
53	0.79864	0.80038	0.80212	0.80386	0.80558	0.80730	0.80902	36
54	0.80902	0.81072	0.81242	0.81412	0.81580	0.81748	0.81915	35°
55°	0.81915	0.82082	0.82248	0.82413	0.82577	0.82741	0.82904	34
56	0.82904	0.83066	0.83228	0.83389	0.83549	0.83708	0.83867	33
57	0.83867	0.84025	0.84182	0.84339	0.84495	0.84650	0.84805	32
58	0.84805	0.84959	0.85112	0.85264	0.85416	0.85567	0.85717	31
59	0.85717	0.85866	0.86015	0.86163	0.86310	0.86457	0.86603	30°
60°	0.86603	0.86748	0.86892	0.87036	0.87178	0.87321	0.87462	29
61	0.87462	0.87603	0.87743	0.87882	0.88020	0.88158	0.88295	28
62	0.88295	0.88431	0.88566	0.88701	0.88835	0.88969	0.89101	27
63	0.89101	0.89232	0.89363	0.89493	0.89623	0.89752	0.89879	26
64	0.89879	0.90007	0.90133	0.90259	0.90383	0.90507	0.90631	25°
65°	0.90631	0.90753	0.90875	0.90996	0.91116	0.91236	0.91355	24
66	0.91355	0.91472	0.91590	0.91706	0.91822	0.91936	0.92050	23
67	0.92050	0.92164	0.92276	0.92388	0.92499	0.92609	0.92718	22
68	0.92718	0.92827	0.92935	0.93042	0.93148	0.93253	0.93358	21
69	0.93358	0.93462	0.93565	0.93667	0.93769	0.93869	0.93969	20°
70°	0.93969	0.94068	0.94167	0.94264	0.94361	0.94457	0.94552	19
71	0.94552	0.94646	0.94740	0.94832	0.94924	0.95015	0.95106	18
72	0.95106	0.95195	0.95284	0.95372	0.95459	0.95545	0.95630	17
73	0.95630	0.95715	0.95799	0.95882	0.95964	0.96046	0.96126	16
74	0.96126	0.96206	0.96285	0.96363	0.96440	0.96517	0.96593	15°
75°	0.96593	0.96667	0.96742	0.96815	0.96887	0.96959	0.97030	14
76	0.97030	0.97100	0.97169	0.97237	0.97304	0.97371	0.97437	13
77	0.97437	0.97502	0.97566	0.97630	0.97692	0.97754	0.97815	12
78	0.97815	0.97875	0.97934	0.97992	0.98050	0.98107	0.98163	11
79	0.98163	0.98218	0.98272	0.98325	0.98378	0.98430	0.98481	10
80°	0.98481	0.98531	0.98580	0.98629	0.98676	0.98723	0.98769	9
81	0.98769	0.98814	0.98858	0.98902	0.98944	0.98986	0.99027	8
82	0.99027	0.99067	0.99106	0.99144	0.99182	0.99219	0.99255	7
83	0.99255	0.99290	0.99324	0.99357	0.99390	0.99421	0.99452	6
84	0.99452	0.99482	0.99511	0.99540	0.99567	0.99594	0.99619	5°
85°	0.99619	0.99644	0.99668	0.99692	0.99714	0.99736	0.99756	4
86	0.99756	0.99776	0.99795	0.99813	0.99831	0.99847	0.99863	3
87	0.99863	0.99878	0.99892	0.99905	0.99917	0.99929	0.99939	2
88	0.99939	0.99949	0.99958	0.99966	0.99973	0.99979	0.99985	1
89	0.99985	0.99989	0.99993	0.99996	0.99998	1.00000	1.00000	0°
	60′	50′	40′	30′	20′	10′	0′	Angle

COSINE

Table XXII.—Natural Tangents and Cotangents (10b)

TANGENT

Angle	0′	10′	20′	30′	40′	50′	60′	
0°	0.00000	0.00291	0.00582	0.00873	0.01164	0.01455	0.01746	89
1	0.01746	0.02036	0.02328	0.02619	0.02910	0.03201	0.03492	88
2	0.03492	0.03783	0.04075	0.04366	0.04658	0.04949	0.05241	87
3	0.05241	0.05533	0.05824	0.06116	0.06408	0.06700	0.06993	86
4	0.06993	0.07285	0.07578	0.07870	0.08163	0.08456	0.08749	85°
5°	0.08749	0.09042	0.09335	0.09629	0.09923	0.10216	0.10510	84
6	0.10510	0.10805	0.11099	0.11394	0.11688	0.11983	0.12278	83
7	0.12278	0.12574	0.12869	0.13165	0.13461	0.13758	0.14054	82
8	0.14054	0.14351	0.14648	0.14945	0.15243	0.15540	0.15838	81
9	0.15838	0.16137	0.16435	0.16734	0.17033	0.17333	0.17633	80°
10°	0.17633	0.17933	0.18233	0.18534	0.18835	0.19136	0.19438	79
11	0.19438	0.19740	0.20042	0.20345	0.20648	0.20952	0.21256	78
12	0.21256	0.21560	0.21864	0.22169	0.22475	0.22781	0.23087	77
13	0.23087	0.23393	0.23700	0.24008	0.24316	0.24624	0.24933	76
14	0.24933	0.25242	0.25552	0.25862	0.26172	0.26483	0.26795	75°
15°	0.26795	0.27107	0.27419	0.27732	0.28046	0.28360	0.28675	74
16	0.28675	0.28990	0.29305	0.29621	0.29938	0.30255	0.30573	73
17	0.30573	0.30891	0.31210	0.31530	0.31850	0.32171	0.32492	72
18	0.32492	0.32814	0.33136	0.33460	0.33783	0.34108	0.34433	71
19	0.34433	0.34758	0.35085	0.35412	0.35740	0.36068	0.36397	70°
20°	0.36397	0.36727	0.37057	0.37388	0.37720	0.38053	0.38386	69
21	0.38386	0.38721	0.39055	0.39391	0.39727	0.40065	0.40403	68
22	0.40403	0.40741	0.41081	0.41421	0.41763	0.42105	0.42447	67
23	0.42447	0.42791	0.43136	0.43481	0.43828	0.44175	0.44523	66
24	0.44523	0.44872	0.45222	0.45573	0.45924	0.46277	0.46631	65°
25°	0.46631	0.46985	0.47341	0.47698	0.48055	0.48414	0.48773	64
26	0.48773	0.49134	0.49495	0.49858	0.50222	0.50587	0.50953	63
27	0.50953	0.51320	0.51688	0.52057	0.52427	0.52798	0.53171	62
28	0.53171	0.53545	0.53920	0.54296	0.54673	0.55051	0.55431	61
29	0.55431	0.55812	0.56194	0.56577	0.56962	0.57348	0.57735	60°
30°	0.57735	0.58124	0.58513	0.58905	0.59297	0.59691	0.60086	59
31	0.60086	0.60483	0.60881	0.61280	0.61681	0.62083	0.62487	58
32	0.62487	0.62892	0.63299	0.63707	0.64117	0.64528	0.64941	57
33	0.64941	0.65355	0.65771	0.66189	0.66608	0.67028	0.67451	56
34	0.67451	0.67875	0.68301	0.68728	0.69157	0.69588	0.70021	55°
35°	0.70021	0.70455	0.70891	0.71329	0.71769	0.72211	0.72654	54
36	0.72654	0.73100	0.73547	0.73996	0.74447	0.74900	0.75355	53
37	0.75355	0.75812	0.76272	0.76733	0.77196	0.77661	0.78129	52
38	0.78129	0.78598	0.79070	0.79544	0.80020	0.80498	0.80978	51
39	0.80978	0.81461	0.81946	0.82434	0.82923	0.83415	0.83910	50°
40°	0.83910	0.84407	0.84906	0.85408	0.85912	0.86419	0.86929	49
41	0.86929	0.87441	0.87955	0.88473	0.88992	0.89515	0.90040	48
42	0.90040	0.90569	0.91099	0.91633	0.92170	0.92709	0.93252	47
43	0.93252	0.93797	0.94345	0.94896	0.95451	0.96008	0.96569	46
44	0.96569	0.97133	0.97700	0.98270	0.98843	0.99420	1.00000	45°
	60′	50′	40′	30′	20′	10′	0′	Angle

COTANGENT

Table XXII.—Natural Tangents and Cotangents (10b)

TANGENT

Angle	0′	10′	20′	30′	40′	50′	60′	
45°	1.00000	1.00583	1.01170	1.01761	1.02355	1.02952	1.03553	44
46	1.03553	1.04158	1.04766	1.05378	1.05994	1.06613	1.07237	43
47	1.07237	1.07864	1.08496	1.09131	1.09770	1.10414	1.11061	42
48	1.11061	1.11713	1.12369	1.13029	1.13694	1.14363	1.15037	41
49	1.15037	1.15715	1.16398	1.17085	1.17777	1.18474	1.19175	40°
50°	1.19175	1.19882	1.20593	1.21310	1.22031	1.22758	1.23490	39
51	1.23490	1.24227	1.24969	1.25717	1.26471	1.27230	1.27994	38
52	1.27994	1.28764	1.29541	1.30323	1.31110	1.31904	1.32704	37
53	1.32704	1.33511	1.34323	1.35142	1.35968	1.36800	1.37638	36
54	1.37638	1.38484	1.39336	1.40195	1.41061	1.41934	1.42815	35°
55°	1.42815	1.43703	1.44598	1.45501	1.46411	1.47330	1.48256	34
56	1.48256	1.49190	1.50133	1.51084	1.52043	1.53010	1.53987	33
57	1.53987	1.54972	1.55966	1.56969	1.57981	1.59002	1.60033	32
58	1.60033	1.61074	1.62125	1.63185	1.64256	1.65337	1.66428	31
59	1.66428	1.67530	1.68643	1.69766	1.70901	1.72047	1.73205	30°
60°	1.73205	1.74375	1.75556	1.76749	1.77955	1.79174	1.80405	29
61	1.80405	1.81649	1.82906	1.84177	1.85462	1.86760	1.88073	28
62	1.88073	1.89400	1.90741	1.92098	1.93470	1.94858	1.96261	27
63	1.96261	1.97680	1.99116	2.00569	2.02039	2.03526	2.05030	26
64	2.05030	2.06553	2.08094	2.09654	2.11233	2.12832	2.14451	25°
65°	2.14451	2.16090	2.17749	2.19430	2.21132	2.22857	2.24604	24
66	2.24604	2.26374	2.28167	2.29984	2.31826	2.33693	2.35585	23
67	2.35585	2.37504	2.39449	2.41421	2.43422	2.45451	2.47509	22
68	2.47509	2.49597	2.51715	2.53865	2.56046	2.58261	2.60509	21
69	2.60509	2.62791	2.65109	2.67462	2.69853	2.72281	2.74748	20°
70°	2.74748	2.77254	2.79802	2.82391	2.85023	2.87700	2.90421	19
71	2.90421	2.93189	2.96004	2.98869	3.01783	3.04749	3.07768	18
72	3.07768	3.10842	3.13972	3.17159	3.20406	3.23714	3.27085	17
73	3.27085	3.30521	3.34023	3.37594	3.41236	3.44951	3.48741	16
74	3.48741	3.52609	3.56557	3.60588	3.64705	3.68909	3.73205	15°
75°	3.73205	3.77595	3.82083	3.86671	3.91364	3.96165	4.01078	14
76	4.01078	4.06107	4.11256	4.16530	4.21933	4.27471	4.33148	13
77	4.33148	4.38969	4.44942	4.51071	4.57363	4.63825	4.70463	12
78	4.70463	4.77286	4.84300	4.91516	4.98940	5.06584	5.14455	11
79	5.14455	5.22566	5.30928	5.39552	5.48451	5.57638	5.67128	10°
80°	5.67128	5.76937	5.87080	5.97576	6.08444	6.19703	6.31375	9
81	6.31375	6.43484	6.56055	6.69116	6.82694	6.96823	7.11537	8
82	7.11537	7.26873	7.42871	7.59575	7.77035	7.95302	8.14435	7
83	8.14435	8.34496	8.55555	8.77689	9.00983	9.25530	9.51436	6
84	9.51436	9.78817	10.0780	10.3854	10.7119	11.0594	11.4301	5°
85°	11.4301	11.8262	12.2505	12.7062	13.1969	13.7267	14.3007	4
86	14.3007	14.9244	15.6048	16.3499	17.1693	18.0750	19.0811	3
87	19.0811	20.2056	21.4704	22.9038	24.5418	26.4316	28.6363	2
88	28.6363	31.2416	34.3678	38.1885	42.9641	49.1039	57.2900	1
89	57.2900	68.7501	85.9398	114.589	171.885	343.774	∞	0°
	60′	50′	40′	30′	20′	10′	0′	Angle

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SECTION 6

PLANNING OF ROADS AND ROAD SYSTEMS

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ROAD SYSTEMS

1. Development of Roads

Historical Development. Roads since the earliest times have been a necessary and important factor in the growth and development of a country. About 200 B. C., Europe, northern Africa, part of Asia Minor and Arabia were traversed by a system of roads, comprising some 48 500 miles, built by the Romans. While the development of many roads has been for purposes of military operations, the great majority have been built for the transportation of materials or persons from one place to another in times of peace. The road systems of Europe have been improved to a much greater extent than those in the United States, mainly because road building in Europe is extensively undertaken by some of the national governments and, furthermore, because the countries were largely settled before the advent of the railroad and hence roads were the only means of intercommunication between inland towns and cities.

The road systems of the United States have grown gradually with the development of the country and as new settlements have been made. The first connecting link between an old and new settlement was simply a path or blazed trail. Later, as necessity demanded, the path was widened to accommodate pack animals and still further improved as the settlements grew and wheeled vehicles came into use. The constant addition of new settlements and the opening up of roads connecting them with the older settlements account for most of the existing roads. Due to the way these systems have gradually developed direct routes between large cities at a

great distance apart are not frequently found, but the route is made up of the connecting roads between the smaller towns situated between the cities. Alignment and grade usually were not given much consideration in laying out the original roads, the main object being to form a connecting link between two places with as little expense and labor as possible.

Lewis, in a report (22) to the 3rd Int. Road Cong. covered the fundamentals of the historical development of highways as follows: "Among the oldest institutions of civilized countries are their highways. Their origin was due to the necessity of traveling and moving materials from one point to another not far distant, usually between farm and market, or between adjacent communities or centers of population. The distances traversed were short, the speed was slow, the methods of transportation were crude, and the total amount of movement was slight. As each additional center of population developed it was connected with the nearest similar center and thus with other centers thru already existing roads. Towns separated by considerable distances were connected with each other by means of the series of local connections, and rarely were direct routes provided between widely separated towns, except in a few cases where the shortest practicable roads between distant points were laid out and constructed for military purposes. In the United States, where centers of population were early established at points remote from each other, such centers were connected by roads which have since developed into important and reasonably direct arteries of traffic, such as those connecting New York with Boston, Albany and Philadelphia. The distances covered by these three roads were, respectively, about 230, 150, and 100 miles. Transcontinental trails followed by those seeking homes in newly developing parts of the country have in comparatively few years become long, direct highways, but important and populous cities which have grown up far from the lines of these trails have not been connected with each other by direct roads. The original highways, whether long or short, were seldom actually constructed; they merely grew; the way was often cleared thru forest, but there was little grading, very slight attempt at drainage, and little more than the native soil in the way of road surface. The tractive force required in proportion to the load was very great, and the gradients were necessarily light. These moderate gradients were not secured by cutting down the hills and filling up the valleys, but by detours, short or long, as the topography required. While new roads have been laid out, they have been made branches from or extensions of these old roads, and surprisingly little has been done toward the rectification of the lines or the betterment of the gradients of what have become trunk highways. The distance traversed by the individual vehicle in a single trip was slight, rarely exceeding 20 miles, while the average distance covered was probably not more than half as great. Since the introduction of self-propelled vehicles, with their greatly increased radius of action, the loss of time, energy and money caused by lack of directness in highways has been more apparent, and it is obvious that any intelligent plan for the improvement and extension of an existing system of roads or the development of a new system must include the correction of alignment in existing roads, and provision for direct routes between important centers."

Status of Roads in the United States. Table I, compiled from records gathered by the U. S. O. P. R., gives for 1914 the mileage of rural and surfaced roads, and other data relative thereto, for each State.

2. Classification of Roads

In the United States there is no national system of roads, altho several schemes of federal aid and of national highways have been proposed. Under the Federal-Aid Road Act of 1916, the United States Government was empowered to extend financial aid, under certain provisions, to the several states for the construction of rural post roads. Several sectional and national organizations have proposed interstate highway systems. The most comprehensive system, aggregating 100 000 miles, is advocated by the National Highways Association.

The construction of roads is therefore undertaken by the states and their

Table I.—Road Mileage in the United States in 1914 (34b)

State	Total Road Mileage	Miles Surfaced	Percentage Surfaced	Total Mileage: Per Sq Mile of Area	Total Mileage: Per 1000 Rural Population	Surfaced Mileage: Per Sq Mile of Area	Surfaced Mileage: Per 1000 Rural Population
Alabama	55 446	4 988	8.99	1.08	31.3	0.097	2.82
Arizona	12 075	253	2.09	0.11	85.5	0.002	1.79
Arkansas	50 743	1 097	2.16	0.96	36.9	0.020	0.80
California	61 039	10 279	16.84	0.39	67.2	0.066	11.32
Colorado	39 780	1 193	3.00	0.38	100.9	0.011	3.02
Connecticut	14 061	2 975	21.16	2.92	122.3	0.617	25.89
Delaware	3 674	243	6.62	1.86	34.9	1.240	2.32
Florida	17 995	2 830	15.72	0.33	33.6	0.052	5.29
Georgia	80 669	12 342	15.30	1.37	38.9	0.210	5.96
Idaho	24 396	679	2.78	0.29	95.4	0.008	2.65
Illinois	95 647	11 606	12.02	1.71	44.2	0.207	5.37
Indiana	73 347	30 962	42.20	2.03	47.1	0.858	19.88
Iowa	104 074	614	0.59	1.87	67.3	0.001	0.39
Kansas	111 052	1 148	1.08	1.35	92.7	0.014	0.96
Kentucky	57 916	12 403	21.40	1.44	33.4	0.308	7.15
Louisiana	24 563	2 067	8.42	0.54	21.1	0.050	1.78
Maine	23 537	2 762	11.74	0.79	65.3	0.092	7.65
Maryland	16 459	2 489	15.10	1.65	25.8	0.250	3.90
Massachusetts	18 681	8 505	45.53	2.32	77.5	1.058	35.29
Michigan	74 190	7 828	10.55	1.29	50.0	0.136	5.28
Minnesota	93 517	3 967	4.24	1.15	76.3	0.036	2.42
Mississippi	45 779	2 133	4.66	0.98	28.8	0.046	1.34
Missouri	96 041	6 712	6.98	1.39	50.6	0.097	3.54
Montana	39 204	609	1.55	0.27	161.5	0.004	2.51
Nebraska	80 272	1 204	1.50	1.04	91.0	0.001	1.36
Nevada	12 182	262	2.14	0.11	177.8	0.002	3.82
New Hampshire	14 020	1 659	11.83	1.55	79.9	0.184	9.47
New Jersey	14 817	5 897	39.80	1.97	23.5	0.784	9.40
New Mexico	11 873	261	2.20	0.09	42.3	0.002	0.93
New York	79 398	15 635	19.60	1.66	41.2	0.328	8.10
North Carolina	50 758	6 003	11.82	1.04	26.8	0.123	3.18
North Dakota	68 796	955	1.38	0.98	138.8	0.013	1.86
Ohio	86 354	30 569	35.16	2.12	41.0	0.750	14.54
Oklahoma	107 916	121	0.11	1.55	80.7	0.002	0.09
Oregon	36 819	4 726	12.83	0.38	100.6	0.049	12.89
Pennsylvania	91 555	9 982	10.90	2.22	30.2	0.220	3.29
Rhode Island	2 170	693	31.95	2.03	120.8	0.649	38.59
South Carolina	42 226	3 270	7.74	1.38	32.7	0.107	2.53
South Dakota	96 306	363	0.37	1.25	189.8	0.004	0.72
Tennessee	46 050	8 102	17.59	1.10	26.4	0.194	4.64
Texas	128 960	10 526	8.16	0.49	43.6	0.401	3.56
Utah	8 810	1 153	13.09	0.11	43.9	0.014	5.76
Vermont	14 249	1 442	10.12	1.56	76.2	0.158	7.71
Virginia	53 388	3 909	7.32	1.32	33.7	0.097	2.46
Washington	42 428	4 922	11.61	0.63	79.0	0.073	9.17
West Virginia	32 024	1 064	3.30	1.33	32.3	0.044	1.07
Wisconsin	75 707	13 399	17.60	1.37	56.9	0.242	10.08
Wyoming	14 797	468	3.10	0.15	147.9	0.005	4.56
United States	2 445 760	257 291	10.52	0.82	49.5	0.086	5.21

subsidiary governments. The road classification common to the United States is usually as follows: state roads, county roads and town roads.

Classification of Pennsylvania Roads by Foster (19). "The highways existing in the state of Pennsylvania may be divided into several classes, namely: The old

Indian and animal trails; the state roads including the provincial highways; the toll roads, or those built by corporations; and the local or township roads.

"The first class, the old Indian and animal trails or roads, usually follow the valleys made by creeks and rivers and run along the line of least resistance, and any change in the alignment will consist, in a great measure, in the elimination of existing crossings or in the necessity of an increased number of crossings of the parallel waterway. Changes will be necessary in order to escape extensive maintenance, due to slips or washouts; on account of the necessity of raising the grade of the highway to a point beyond highwater; and, in order to eliminate the usual heavy grade that is found where a road has followed a valley to its head.

"The second class, or state roads, are those highways known as stage roads and offer a wide field for relocation, as this type of highway was constructed seemingly without regard to economy, safety, or comfort, and, apparently laid out with a view of obtaining the most direct line between two points. The changes most readily determined on this class of highways, consist of relocating them around the bases of hills and along the ridges, thus eliminating the steep grades, with probably very little if any increased length, and at little cost or less cost than the heavy construction work and excessive maintenance charges necessary in allowing them to remain where they are. The provincial roads also coming under the class of state highways need little realignment, except in instances where a relocation is necessary on account of some foreign development which has caused a divergence from the original alignment; and the amount of relocation and the extent thereof will depend in a great measure on the money available for property damages, as this type of road, owing to its long number of years of use, will be found to traverse sections of the country which have been more or less built up.

"The third class, toll-roads, were built for corporations and were constructed with economy as to maintenance; and the thoroness of their construction and the extent to which they were improved were dependent on the expected monetary return from travel over them, and where competing companies operated, greater attention was given to details of alignment and grade.

"The fourth class, or the local highways, were laid out in most part by county engineers and boards of viewers and were surveyed primarily to provide the greatest economy in labor of construction, or were bound, by decision of the board of viewers, to follow existing property lines. In other instances, such roads have been properly located by the county engineer, but, on account of the construction being left entirely to the local authorities, original grades and lines were not followed, and while plan and profile probably still exist, no proper physical location can possibly be made, and the present traveled road has become a permanent highway, and property rights, in many instances, have passed, using the center line of such existing highway as a boundary. In this class of highways, realignment will consist in the abolition of sharp turns and steep grades by correct location without regard to property lines."

Classification of California Roads (18a). "The primary demand of the California Highway Act is for trunk line construction; for two roughly parallel lines, one thru the coast counties and the other thru the great interior valleys, the Sacramento and the San Joaquin, serving county seats and connecting centers of population by the most direct and practical routes. In the skeleton system of highways outlined by the act, these constitute the backbone. The secondary demand of the act is for lateral road construction; to connect with the highways those county seats which are not directly served by either trunk line.

"The Highway Commission and its engineers in charge in each division have finished 2000 miles, traveling by automobile, thru these mountain counties, studying their location, needs and desires at first hand. These county seats, for the most part, lie to the east of the Sierras. Their connecting roads to the valley cross elevations of from 4500 to 7500 ft, and are snow blocked for months on end. The problem is to build laterals to these points which will utilize the lowest passes thru the mountains and be useable thru the winter months. The relation of the lateral to the trunk line expresses itself also in character of construction. The standards of trunk line construction have been set high, no grade in excess of 7%, no curves with shorter radii than 50 ft, a 21-ft roadbed, and with ideal alignment, etc. The type of construction has been fixed—the concrete base, permanent type. The lateral roads, however, warrant a much more flexible policy. Some of them will carry sufficient traffic to

warrant trunk line type of construction. On the purely mountain laterals such construction would be folly. No one wants, expects, or needs city streets thru the Sierras. An accurate study, therefore, of this problem will demonstrate the necessity of varying situations. Grades steeper than on the main routes, narrower road-beds, surfacing of native materials, and similar reasonable economies will be necessary in handling this lateral problem without a prohibitive cost."

3. Planning of Road Systems

Fundamental Considerations. In a report to the 3rd Int. Road Cong. Lewis (22) states that "The most essential considerations which should govern the planning of the individual road or a complete highway system may be briefly summarized as follows:

1. The road, while not monotonously straight, should be as direct as the topography and limiting grades will permit.
2. Trunk lines, articulated with those of an adjoining jurisdiction, should form the basis of a complete road system.
3. Detours from the general direction of trunk lines to reach unimportant towns are not justified; such towns can be served by branch roads.
4. The principal streets of a city should form a part of the trunk system of the territory in which such city is located. Facility of movement between the city and the surrounding country and neighboring towns is essential.
5. The principal highways between neighboring towns should connect directly with their most important and dignified thorofares.
6. Roads should increase in width as they approach important towns, so that as the towns grow outward along these roads it will not be necessary to incur great expense in widening them.
7. In establishing adequate roads radiating from important cities it is unnecessary to undertake expensive widenings of the streets of small towns or villages. By-pass roads around them will answer the purpose.
8. At crossings or junctions of rural highways sufficient space should be added to the road to afford a view of approaching vehicles. Curves should be used instead of abrupt deflections. In city streets a widening at important junctions is always desirable.
9. Tramways are inevitable in city streets, and the best location for them is in the middle of the roadway. When they follow rural highways, they should be so separated from the traveled road that vehicles cannot pass from road to tracks, and they should never cross the highway at grade.
10. Roads should be made interesting where possible. Picturesque vistas and extensive outlooks are desirable as well as easy gradients and a smooth surface. The highway should promote health and pleasure, as well as business."

Selection of Routes on Maps. A map showing the plan of all the roads of the state is a great aid in selecting and classifying the roads. If the map is one giving contours and other topography similar to those prepared by the U. S. Geol. Survey, it will save considerable time that otherwise might have to be spent in making preliminary investigations. With this map the main traffic routes or those which serve as thru routes between important points within the state or as parts of thru routes to important points in adjoining states can be temporarily selected. Such roads will be classed as STATE ROADS. There may be instances where the same terminals can be reached by different routes but it will not be possible to

tell from the map which route should be selected. The COUNTY ROADS will comprise the important roads of the county. They will be those roads, not included in the state system connecting the important towns, of particular value to the county as a whole in its development. The county roads will be selected from the map in the same manner as the roads of the state system were. All of the remaining roads will be classed as TOWN ROADS being local in character. If insufficient money is available for the construction of all of them, the important roads should be selected for the town system. There will be some overlapping of the three classes and the distinction between the roads in the county and town systems may not be as clear at first sight as it is in the case of the state and county systems.

A Reconnaissance should be made of each route for each of the systems and observations made in a general way regarding the several points as follows: general alignment, possibility of detours to overcome bad alignment or grade, general topography, geological structure, maximum gradients, foundations, drainage, availability of material for construction, structures, grade crossings, and their possible elimination, the connection of the route with its terminals and the connection of the thru routes with the main highways of other states. Where there is a choice of routes, a reconnaissance will sometimes determine without further investigations which route it is advisable to adopt.

Traffic Census. When a reconnaissance has been made and the selection of routes modified in accordance with the information obtained, a traffic census should be taken in such a manner that the amount and kind of traffic using the roads may be known. A traffic census in a large measure determines to what class a road belongs. From the use of a map alone it might be decided that a road should be classed as a county road while the traffic census would show that it is used largely by thru traffic and should really be classed in the state system. Furthermore it may be found from a traffic census that some roads are not so important as their location on the map would indicate. In the case of some of the middle western states, the roads of which follow the section lines of the U. S. Public Land Surveys, it is very difficult to determine which are the important roads without a traffic census, since the chessboard plan of the roads permits a wide choice of routes between two points. For instance, in Illinois it was found from a traffic census that 15 000 miles out of the 95 000 miles of highways within the state would carry 90% of all the traffic. Due consideration should be given to the change in traffic due to a road's improvement. For example, the improvement of one route might divert traffic from some other route with a consequent increase in the one case and a decrease in the other from results obtained in the traffic census. It is apparent that when the results of the traffic census have been studied and analyzed, a further revision of the routes chosen for the different systems can be made. The various methods of taking traffic censuses and interpretation of the results are given in Sect. 4.

Financial Considerations. If the problem is studied with regard to the considerations previously mentioned, a comprehensive system of roads will result. The cost of each system should be borne by the state, county and town in a manner that would be equitable. If the state pays the entire cost of the roads on the state system, the construction of the system will generally be more expeditiously and efficiently carried out than is the case where the state pays a part and the town or county the remainder.

The present state laws in many instances prevent the adoption of an ideal system of roads. Where the law states that appropriations shall be divided by some pro rata scheme amongst the different towns and counties, many sections of road will be built as state roads that are local in character and should belong to the county or town system. See Sect. 28.

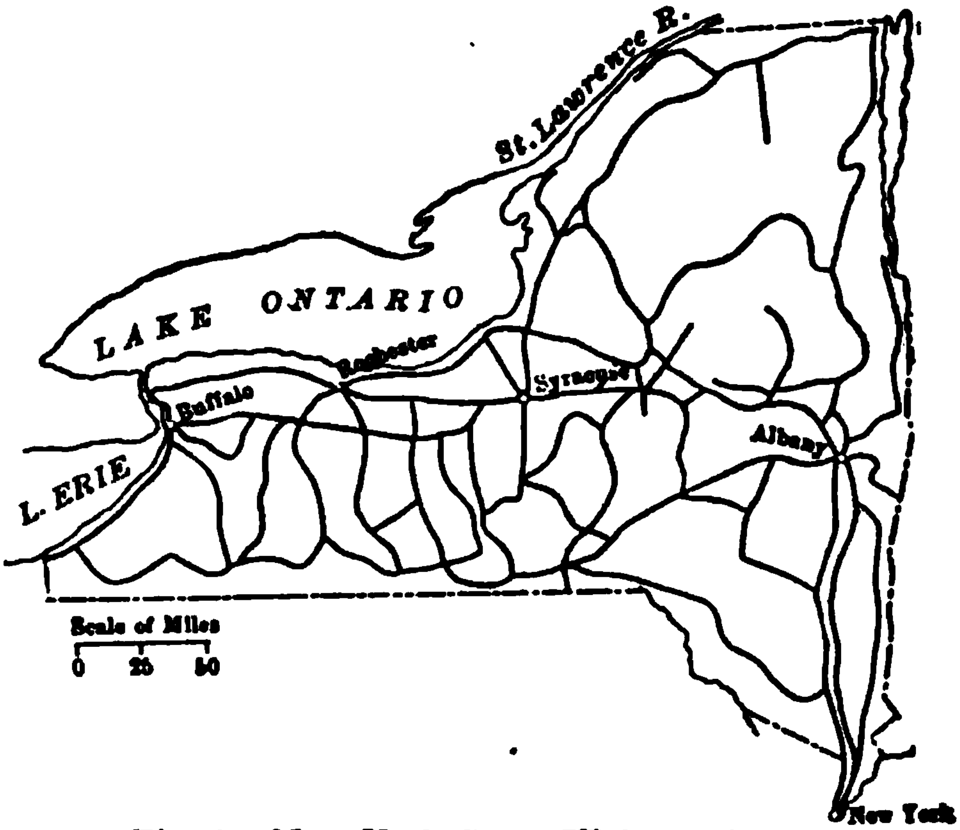


Fig. 1. New York State Highway System

Example of Inefficient Development of Highways by Uneconomical Use of State Appropriations. Moore (8) states that "no haphazard, disjointed method of improving main roads, without a definite plan by which the work of today will eventually become a part of a complete system of intercounty highways, will prove satisfactory. The experience in Pennsylvania, where the main roads are designated by law, indicates that a legislature will relieve itself of needless trouble and the taxpayers of needless waste of money by entrusting the selection of the main roads to the state highway department. The Pennsylvania legislature designated 10 200 miles of its roads as state highways. Only a small part of this mileage has been improved, and the roads selected do not form a satisfactory system. Moreover, the length of the roads is altogether too great for the money available for their improvement. The result is stated by Chief Engineer William D. Uhler of the State Highway Department as follows: 'During 1915 the department spent about $4 500 000 in maintaining this mileage and during 1916 it will spend about $3 000 000, making a total of $7 500 000 spent on the roads in 2 years, with nothing of any great moment in the way of permanent improvement to show for it. Had it been possible to spend this $7 500 000 in permanent construction, from 500 to 600 miles of highways could have been improved during 1915 and 1916, which added to the 1880 miles already improved, would have furnished a satisfactory nucleus for the permanent highway system of the state.' "

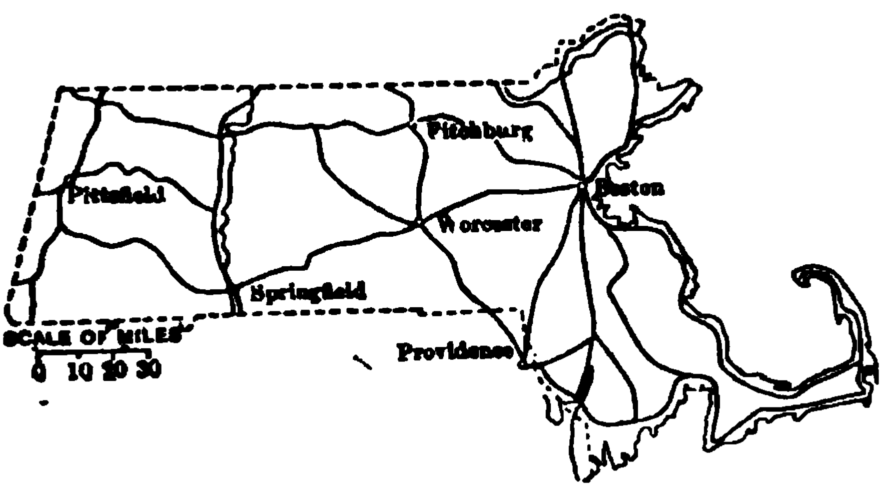


Fig. 2. Principal State Roads of Massachusetts

Form of the System. The system will generally approximate either the radial or the rectangular form with diagonal lines. The first form is perhaps more common in the eastern states, while the second is found in those states where the roads follow the section lines. Fig. 1 shows the system of state roads in New York, the county and town roads not being shown. The roads radiating from some of the large centers will be noted. Fig. 2 shows the system of the principal state roads

in Massachusetts. Fig. 3 shows the existing roads in Vermilion County, Illinois. Here the rectangular system typical of road layouts in Illinois will be noted. Fig. 4 shows a portion of the French road system in the north of France.

THE INDIVIDUAL ROAD

4. Location

The principles and methods advocated in connection with the planning of road systems, as contained in Art. 3, apply, in general, to the determination of the most efficient and economical location of the individual road. The preliminary investigations which should be made, prior to the final selection of a location, are given in detail in Sect. 4.

Necessity for New Locations. Altho the greater part of the planning of roads consists in improving those already in existence, instances often arise, particularly in mountainous and sparsely settled districts, where an entirely new layout is advisable. Old roads were located mainly with the idea of securing a route with as little expenditure of money as possible. Grades, alignment and distance were rarely considered. An improved road should be so designed as to keep the maximum grades within a reasonable limit, with easy curves and with a directness of route consistent with economy.

Fig. 3. Existing Roads in Vermilion County, Ill

To improve the old location and obtain a road having grades and curves within the limits desired might be a prohibitive expense. It might be found that the limiting curves and grades could be obtained on the new location with a consequent shortening of the distance. The saving in distance would either be a direct saving in the expense of constructing

Fig. 4. Highway System of a Section of Northern France

the old location or would allow a more direct route to be built with better lines and grades at an expense not greater than that to construct the old location. On the other hand, the new location might increase the distance somewhat but the saving in constructing the road on the new location with limiting grades and easy curves would more than pay for the increase in distance. The old location might present difficulties in the way of many stream crossings where a direct saving in the number of crossings could be effected in a new location. A more suitable foundation for the roadway might be obtained by choosing a new location if the foundation conditions on the old location were poor. Perhaps the old location of the road might be fairly good with a few exceptions and if short detours were made at these points, the desired improvement in location could be accomplished with economical and satisfactory results. In areas which are thickly settled, the abandonment of the old location for any great distance cannot usually be accomplished with as much freedom as where the important terminals are a long distance apart, since the question of land damages becomes a very important consideration. Grade crossings at railroads are always a source of danger to the users of the highway. Altho it is not always practical to eliminate all of them, frequently it is possible to do away with some of them by changing the location of the road where instances of the old road crossing and recrossing the railroad occur.

By-Pass Roads. It frequently happens in planning a road system, that the principal street of a small village or town will be part of one of the main routes of the state system. The village street may not have sufficient width to take the traffic that the road will be obliged to accommodate and the expense of widening the local street might be so great as to be prohibitive. One solution of the problem is to construct the main highway on a slight detour so that the narrow local street will be avoided. This method of constructing by-pass roads has been employed in many of the old towns of northern France. The by-pass roads in these instances pass outside of the villages and towns and are constructed to accommodate the traffic to which they will be subjected. Such a scheme, however, generally is not adopted where local interests do not care to have the thru traffic pass outside the town.

Report by British Engineers (13). "The deflection of thru traffic from comparatively crowded and narrow business streets of our villages to new roads to be constructed thru virgin land is sometimes opposed by those who have business premises on the route and who fear that they will be affected financially. This might have been largely so in the old days of slow traffic but it is much less so in these days of fast motor traffic. Indeed it may be an advantage to separate a shopping street and the business center from the main thorofare provided for fast traffic. Generally speaking, considerations of engineering, architecture and economy will, it is thought, lead to the construction of new by-pass roads round rather than thru the developed portions of villages and small towns."

Conclusion Adopted by 3rd Int. Road Cong. (32). "As a general principle, it is better that new main roads be constructed to pass outside rather than thru towns, and where an existing main road passing thru a town is unsatisfactory for thru traffic, it is often better, in preference to widening an existing narrow main road thru the center of a town, that new roads should be planned according to the principles of the science of town planning."

Methods of Work. The method followed in locating a new highway or relocating an old one is the same as in railroad location. A study of the area should be made with the help of maps if such can be obtained. A map showing the contours or one with only the water courses on it will be of great assistance. A reconnaissance should be made of different possible routes. Preliminary surveys would be made and the final selection of the route made by comparing the costs and advantages of the different locations. A thoro reconnaissance where the country is particularly rough will generally save much expense in making subsequent surveys.

The measurements taken in the reconnaissance survey would be very approximate and frequently no instruments at all would be employed. The following instruments are useful in reconnaissance work: The aneroid barometer and a hand level for measuring heights roughly, a small compass for measuring angles and the pedometer for measuring distances. The pedometer is similar to a watch but only ticks at every step of the person who carries it and thus records the distance as he walks. The preliminary surveys would be made by methods described in Sect. 5, except that time would usually not be spent in running in curves and the methods described would be modified somewhat for the sake of speed. In the case of short detours the advantages of different lines can sometimes be readily compared on the ground and only one survey may be required to obtain all the information necessary.

General Principles of New Location. Points thru which the road must pass are called ruling points. As illustration of ruling points, the following are cited: Places of importance along the road and its terminals, gaps or low points in ranges of hills, crossings at streams suitable for a bridge, intersections with railroads at points so that grade crossings can be avoided if possible, and on scenic highways points on tops of ridges that give a commanding view of the surrounding country. As a general rule, if a road follows the valley of a stream it will pass the ridges at the lowest points and it will be feasible to build it with moderate grades. While the straight line is the shortest and most direct route between two points, it is not always the best one to build. Expense is usually the most important factor to be considered with regard to questions of alignment. It is impractical in exceedingly rugged country to build a straight road for any great length. In fact, such a requirement is not essential. Curves, provided they are not too sharp, are rather to be desired than avoided. There will be instances where by putting a curve in the line, the tangents may be swung so as to avoid a bad foundation, a summit or a deep ravine, which would considerably add to the expense of construction if the road was carried straight across it. When the road follows a valley bottom, the cost of winding it in and out around the bases of the ravines and spurs should be compared with the cost of making it a straight line. If the curves are not too sharp, the first method will probably be the cheaper and much more picturesque. In crossing from one side of a valley to the other, the cheapest crossing will usually be towards the upstream end of the valley; it is at this point that the sides of the valley are nearer together. The valley may narrow towards the downstream end or an intervening ridge may come between the sides of the valley which might make the crossing at such a point less expensive than at the upper end of the valley. Where two points on either side of a ridge are to be connected, the crossing is generally most economically made thru the low point of the ridge or the gap. If two points are to be joined on the same side of a ridge halfway down its slope, it is usually more economical to construct the road either along the bottom or the top of the ridge and connect its ends with the two points halfway down the ridge than it is to build a straight road across the face of the ridge between the two points. The same principles mentioned above apply to making detours but as the detours are usually of comparatively small extent, the problem is not so difficult.

5. Alignment

General Principles. It has been previously pointed out that the straight line furnishes the most direct and the shortest distance between two points. It is possible to secure long straight roads at a reasonable cost in some of the western states where the topography is generally flat and the roads

are laid out on the section lines of the Public Land Surveys. Directness of route is always desirable but an absolutely straight road built for a long distance without any curves is not a good one from the æsthetic point of view. In country where the topography is rugged, directness of route has to be sacrificed for other considerations. The expense of building on a straight line is prohibitive if grades are adopted consistent with good practice. Questions of foundation, drainage and property damage have to be considered as to their influence on the cost of construction. The kind of traffic that predominates on the road will have some bearing as to the relation between line and grade. If horse-drawn traffic predominates, alignment should be sacrificed for grade while if motor vehicles constitute the greater part of the traffic, grades are not of so much relative importance. The alignment, therefore, usually is made up of a series of tangents connected by curves. As far as possible the alignment at bridges of any kind should be straight across the bridge and for a short distance either side of it so that good approaches may be obtained.

The Improvement of the Alignment of Existing Roads forms the greater part of the work. The alignment of the old travelled way may be greatly improved by a judicious choice of tangents to eliminate the general sinuosity of the old line, and by flattening out or widening sharp curves. Changes of this character can generally be effected within the limits of the old right-of-way. Short detours are made for purposes of making the road more direct, eliminating bad grades or other features which would greatly increase the expense of construction.

Illinois Practice, as typical of that of the Middle West is described as follows by Bilger (14c). "In the prairie states the general features of highway alignment as originally established, in most cases, will meet satisfactorily the requirements of modern traffic. These highways as a rule follow the section lines east and west, and north and south, and are straight. Because of the unusually favorable conditions afforded by the topography and because also of the fact that practically all parts of the country could be utilized for agricultural purposes, a very large mileage of highways was laid out in the states of the Mississippi Valley.

"Marked improvement can be effected in small details that will tend greatly toward the general safety and comfort of the traveling public. For example, at all abrupt angles in the right-of-way, and particularly those approaching 90°, greater safety of travel can be brought about by simply procuring enough additional right-of-way to permit moving the inner fence corner a distance of only 30 or 40 ft. By so doing, the radius of the curve can be considerably lengthened and a much better view provided. Travel is benefited out of all proportion to the cost of the little piece of land. In order that this additional right-of-way at the corner may be utilized to the utmost, it is necessary that all vegetation be kept down and that signboards, if any, be transferred elsewhere.

Fig. 5. Recommended Curve for 90° Turns

"A typical 90° angle in a highway is shown in Fig. 5, similar to which there must be more than 100 000 in Illinois alone. To keep the improvement at the corner within the 50-ft right-of-way lines would require a curve having only a 52.9 ft radius, and the clear sight provided for the traveler would be only 70 ft. As contrasted with this, notice the advantages afforded by acquiring the piece of land *KLMN*,

which contains 0.055 acres and would cost, at the rate of $300 per acre, only $16.50. The longer curve provides an outlook of 142 ft, as against the 70 ft for the other. At the same time it shortens the pavement from *a* to *b* by an amount sufficient to save 40.6 sq yd for a 15-ft pavement, about $70 on a brick pavement and $50 on one of concrete, which is about three times a reasonable price for the land. In addition to this, the right-of-way is not contracted at the corner as it is by the shorter radius curve, so that the 17.5-ft margin between the inner edge of the pavement and the property line is preserved for use as an earth road around the corner as well as on tangents. Moreover the land *KLMN* because of its corner location, is practically valueless for agricultural purposes.

"At all cross roads additional land should be provided by moving the fences back to include the land at the four corners within the limits of the right-of-way, as proposed in the sketch. This brings the control of the corners within the authority of the road officials, who can have removed all vegetation that obstructs the view of the approaches. Where there is an angle greater than 45° in the alignment and the improvement at this place is on an embankment higher than, say, 4 ft, there should be provided on the outside of the curve a substantial-looking guardrail painted white, to serve as a warning to traffic."

Curves. The straight portions of alignment are joined together usually by circular curves. As a general rule long straight tangents should be joined by curves of large radius. Sharp curves should be eliminated or flattened as much as possible if the road is subjected to a combination horse-drawn and motor vehicle traffic. For horse-drawn vehicles sharp curves are not dangerous, but where motor vehicle traffic occurs, sharp curves become exceedingly dangerous. Moreover, the vehicles disintegrate the surface of the roadway on a sharp curve more than where the curve is built with a larger radius. In level and slightly hilly country it is generally possible to obtain curves of proper radius without undue expense. In mountainous districts where steep grades are encountered, the cost of construction will increase very rapidly with the length of the radius of the curve and the curves will have to be made as sharp as the traffic, combined with the costs of construction, will permit. The speed of motor vehicles is considerably reduced both in ascending and descending steep grades, hence, if sharper curves have to be used in such instances, they are not so dangerous as on level stretches.

Minimum Radius. The minimum radius of curves will depend upon the width of roadway and the character of the vehicles upon the road. A 12-ft width requires a radius of about 105 ft to permit a four-horse team and vehicle of a total length of about 50 ft to keep upon the roadway. This radius decreases as the width of road increases so that on an 18-ft roadway, the required radius would be about 77 ft. The minimum radius of the center line for different widths may be approximately calculated from the formula $r = l^2/2w$, where r is the radius of the center line, l the length of team and vehicle, w is the width of roadway (see Fig. 6). One pair of horses will occupy a length of about 13 ft ahead of the wagon and each additional pair 10 ft more if hitched ahead. The length occupied by a wagon or truck varies from about 10 ft for the bottom dump wagon to as much as 50 ft for trucks hauling poles, and in the latter case, the poles, if longer than 50 ft, will extend beyond the trucks. The minimum radius as given by the above formula assumes that the team and wagon are in the same straight line and that the full width of roadway is occupied in going around the curve. Altho it is generally possible to cramp the front wheels and swing the horses towards the inside of the curve, very little clearance for passing would be

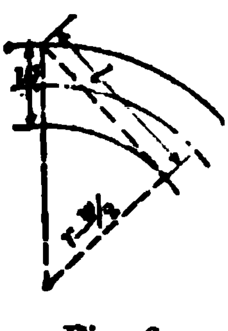


Fig. 6

secured if the radius of the curve is determined entirely by the above formula. One common method of providing more clearance on sharp curves is to widen the roadway on the inside of the curve as shown in Figs. 5 and 7.

The minimum radius of curves recommended by the 1st Int. Road Cong., 1908, is 164 ft. Altho this would be an excellent limit to approach as an ideal, it frequently happens in country of rugged topography that curves are used having a radius as low as 50 to 60 ft. In France a radius of 165 ft is used as a minimum for curves on the national roads except in extreme cases when it is shortened to 100 ft. On the district roads the minimum radius is 50 ft. The practice in Austria is to make the minimum radius from 80 to 160 ft on the principal roads, from 65 to 95 ft on the district roads, and on wagon roads as low as 32 ft. A radius of 95 ft is recommended as being a minimum for roads used by wagons hauling long timbers. In New York State the practice is to make the minimum radius 200 ft wherever possible. It was the recommendation of the 1st Int. Road Cong. that transition curves should be placed between each end of the circular curve and the adjoining tangent to reduce the abruptness of change from a straight line to curve. The practice of this refinement in highway construction has not been generally adopted. Reversed curves should be joined together by a common tangent not less than 50 ft in length.

Clear Sight at Curves. There should be a clear sight distance around the curve of at least 300 ft so that the driver of a motor vehicle can see another vehicle traveling in the same or opposite direction and have sufficient distance in which to bring his vehicle to a stop if necessary. Clearing away the brush and small growth at the sides of the road, or removing a wall or a fence, will frequently accomplish the object sought. Where the bank on the inside of the curve is much above the grade of the road and the curve is very sharp, it may be necessary to cut into the side of the bank at a height equal to the average line of vision of the persons on the road when driving.

Grade Crossings and Their Elimination. All grade crossings of railroads should be eliminated if possible. In thickly settled districts it is not often practical to do this except at great expense. The road may be made to pass under or over the railroad. A new location of the road for a short distance near the point of crossing may present many advantages and considerably reduce the cost of eliminating the crossing on the old location. Where the road crosses under the railroad a minimum clearance of about 14 ft is usually required between the bottom of the bridge and the high point of the crown of the road. The right-angle distance between the faces of the abutments of the bridge depends upon the width of roadway and sidewalks if there are any. Where the road crosses over the railroad a minimum clearance of about 21 ft from the bottom of the bridge to the top of rail is required.

Illinois Practice as described by Bilger (14c) is as follows: "In the vicinity of crossings the improvement should be such as to provide an unobstructed view along the track for a distance of at least 1000 ft each way, and this view should be enjoyed along a length of highway extending a distance of at least 300 ft on each side of the crossing. It is particularly important that there be provided accommodations for two vehicles to pass with entire safety and comfort at the crossing, requiring never less than 18 ft and the highway for a distance of 50 ft or more on each side of the crossing should be practically level or should at least have a very easy grade, say not steeper than about 2%. Much destruction of both life and property is caused by motor vehicles taking a run on the steep grades up to the crossing and then stalling the engine on the track. Occasionally two vehicles will make a run from the opposite sides of the crossing and upon reaching it find that the highway does not have sufficient width for passing."

Grade Crossing Abolition Design as recommended by Reilly (29). "The following is given as an instance of how some of the main features of a plan are adopted.

The railroad, since it pays the greatest portion of the cost, asks, as a rule, for a 5 or 6% street gradient. For traffic reasons the city usually objects to anything over 3%. The result in many cases is a compromise, streets on main thorofares being built with not over 3% grades, other streets not on main thorofares with as high as 7% grades. In one case, in Fall River, Mass., 12% was allowed on account of the fact that this gradient existed on adjacent streets. The question of land damage enters into this question of street grades, and the two should be considered together. As a general rule, when land damage is high, street grades are heavy, and when land damage is low, street grades are low.

"The question as to whether the street is to cross over the railroad or vice-versa is determined by considerations of economy. Where several crossings are to be eliminated which are fairly close together, the railroad can be raised above the streets or depressed below them. It is not usually economical to depress the railroad. The important elements which determine track elevation, or street elevation or depression, are accessibility of dump for excavated material, the number and length of bridges crossing the railroad, the length of haul to borrow pit, drainage of railroad if depressed, the drainage of streets if depressed, and the architectural question of civic beauty. In the case of the elimination of a single crossing, railroad elevation or depression is not economical since the railroad grades are usually limited to 0.57%, while street grades vary from 2 to 7%. The result is the elevation or depression of the street. This applies not only to a single isolated crossing, but also to the case where several crossings are so far apart that the cost of railroad elevation or depression is high.

"Each particular problem must be studied carefully before any plan is adopted. Estimates of cost should be made, if necessary, to determine which of the following methods should be used: First, railroad elevation; second, railroad depression; third, street elevation; fourth, street depression; or a combination of railroad elevation with street depression or vice-versa. It must always be borne in mind, that, if railroad depression is adopted, the track must be lowered about 21 ft, 18 ft for clearance and 3 ft for bridge floors, while if track elevation is used, there is a change in grade to be made of about 17 ft, 14 for clearance and 3 ft for bridge floors. Except in the case of sidetracks, which may be made 16 ft, these clearances are required in Massachusetts, unless authorized otherwise by the Public Service Comm.

"The following is a recapitulation of the points to be observed in designing or criticising the design of a grade abolition project: (1) Cost; (2) discontinuance of important public ways or continuance of same involving real damage to property without redress at law; (3) drainage, railroad and highway; (4) sewage flow, pipe changes, etc; (5) street junction, avoidance of danger points and pockets; (6) minimum of taxable property to be devoted to new streets and ways; (7) traffic routes, vehicular and street railway, distances, grades and maximum avoidance of curves; (8) railroad grades should be slight at stations; (9) highway grades; (10) accessibility of stations to traffic, vehicular, street railway and foot; (a) in grades, elevations and layout, (b) station driveways and carriage yards; (11) industrial sidetracks; (12) bridge headroom; (13) minimum of land damage; (14) maintenance of traffic during construction; (15) bridges and other structures, strength, permanence, waterproofing; (16) apportionment of work; (17) betterments."

6. Grades

Longitudinal Grade. The general topographical condition of the country thru which the road passes and the amount and character of the traffic to which it is expected the road will be subjected will largely influence the amount of grading to be done in the improvement of a road. The maximum grade in a road will limit the maximum load which can be hauled over it and is called the ruling grade. A descending grade should not be used in a line where the general tendency of the topography is rising and an ascending grade should not be used in a line where the general topography is falling. The cost of an increase of distance, due to securing reduced grades by going around a hill, should be compared with the cost of securing the same rates of grade going over the hill. It will generally be found that a considerable increase in distance is permissible before the costs of

the two schemes become equal. Roads with gently undulating grades have erroneously been thought by some to be less tiring to horses than a road with a perfectly level grade. Undulating grades can sometimes be used to advantage in reducing the amount of grading, but judgment should be exercised in their adoption or the road may have an objectionable appearance. For instance a grade line on a straight stretch of road in flat country composed of several successive short grades 100 to 200 ft long alternately rising and falling will give the road a decidedly humpy appearance. A change from a rising to a falling grade can sometimes be made to advantage at a curve without detracting from the road's appearance, provided the change is not too abrupt. Altho it is of considerable advantage to obtain a grade which will make the cuts and fills balance, other considerations are often of far greater importance. The grade must be so established as not to cause damage to the surrounding property, and so that proper drainage and proper foundation can be obtained. The grade may have to be raised in order to obtain a satisfactory bottom underneath the road. Again, a considerable saving may be effected by taking advantage of an old surface as a foundation, the new grade being established so as to disturb the old road as little as possible. The grades of bridges across streams and those of railroad crossings and intersecting roads will have to be met in establishing the grade of the road. The elevation or high water mark will also have to be considered in cases where the road crosses a water course. In wide level valleys subject to floods, if it is impossible to make the bridge opening and channel sufficiently large to carry the flood stream, the grade should be made so that the water can overflow the road at certain points. The low places would be so located as to cause as little damage as possible to adjacent property and be long and shallow, so that the water can overflow them with as little velocity as possible. In the case of narrow valleys and streams having a swift velocity, it is usually advisable to establish the grade above the reach of high water. Since maximum floods occur only at relatively long periods apart, it may be more economical to construct the crossing to take care of the average high water and reconstruct it from time to time in the same manner if destroyed by excessive high water than to construct the crossing in the first place above excessive high water. The comparative merits of the two schemes may be obtained by computing both schemes on a capitalized cost basis. If any danger to human life is involved, however, due weight should be given to that scheme which makes conditions the safest. Grades should be connected with vertical curves where necessary, see Art. 30, Sect. 5. Drawing the grade on the profile is explained in Art. 30, Sect. 5. General considerations regarding grade are also treated in Sect. 4.

From the standpoint of economical hauling, a perfectly level road is the most desirable. Level stretches of road are only possible in flat country and are rarely built except for very short sections on account of the difficulties presented in draining the road. A limiting grade, adopted as a maximum, should be adhered to except in occasional instances demanding special consideration. The limiting grade may be made a variable one, depending upon the character of the topography, whether flat or rugged, and the class of road. The funds available for construction work also influence to some extent the rate of grade which it is advisable to adopt as a maximum. The maximum grade as an ascending grade chiefly affects the load that can be hauled while as a descending grade the matter of

safety is of more importance. Money spent in greatly reducing the grades of a road when one long grade occurs, which is the ruling grade, is usually wasted. There may be local conditions, however, which would warrant such an expenditure. The direction in which the majority of the loads are hauled will have some influence in establishing the grade since it might be possible to establish the maximum grade so as to be down hill for the loaded vehicles.

Penn. State Highway Dept. Instructions (9). "It is well to keep in mind the direction of the heavy hauling and, if topographically possible and practicable, to arrange the grade line so that the maximum grades will be descending grades in this direction. If we have a certain market or shipping center to reach, the profile should be carefully studied to ascertain the maximum grade along the road which cannot be eliminated for topographical or other reasons. With this information as a guide, considerable money can be saved by avoiding ruthless slashing of knolls and excessive filling in other places. It is readily seen that considerable study and forethought must be given to this question. Grades should be established so as not to damage abutting property unnecessarily and regulated to provide properly for drainage, underdrainage, and foundation. On existing old stone roads a considerable saving may be effected by following the old road surface as nearly as possible so as not to disturb this as a foundation."

Road Resistances. The tractive force or pull exerted in moving a load on wheels over a road is consumed in overcoming three kinds of resistances, namely, axle friction, rolling resistances, and grade resistances. Axle friction, as its name implies, depends upon the friction between the axle and its bearing. It varies with the load on the wheels, the nature of the lubricant used and with the kind of materials which compose the bearing surfaces. The rolling resistance varies depending upon the diameter of wheel, the tire width, the speed of the vehicle and the condition of the surface over which the load is being hauled. The grade resistance may be expressed by the formula $r = w\,p$, in which r represents the resistance in pounds, w, the weight of the load in pounds, and p the percent of grade expressed as hundredths. If r is expressed as pounds per ton of load, then $r = 2000\,p$. For tables giving the rolling resistance for wagons in pounds per ton of load for different pavements, see references in Sect. 4. The wide range in experimental data is partly due to using wheels of different diameters, tires of various widths and the varying condition of the surfaces of pavements. Axle friction is so small that it can be neglected. Assume 40 lb per ton as an average value for rolling resistance on sheet-asphalt, brick, all forms of broken stone roads, including those bound together with bituminous materials, stone block, and wood block and 125 lb per ton as an average value for earth roads. Grade resistance in pounds per ton of load for different percents of grade may be computed from the formula given above. The rolling resistance plus the grade resistance will equal the total resistance in pounds per ton of load. Dividing the tractive effort for any grade by the total resistance for that grade will give the amount of load which can be drawn up it. It has been shown by actual test that a horse when working steadily for 10 hr can exert a pull of $\frac{1}{10}$ of his weight, or 120 lb, if it weighs 1200 lb. For a distance of about 100 ft it can exert a pull of $\frac{5}{10}$ its weight, provided a good foothold is available. The tractive force for a 2400-lb team on a level may be taken as 240 lb, while on a grade it will be a variable force depending upon the percent of grade since the team has to overcome the grade resistance due to its own weight or 2400 p, where p is the percent of grade. It is a fact that a team can pull with a force of 600 lb. which is $\frac{1}{4}$ its weight, for a distance of about 1000 ft. If the grade is longer than this, the team will have to stop and rest.

Example. Find the load a team can draw up a macadam road on a 3% grade and on a 10% grade.

3% Grade

Rolling resistance......	40 lb
Grade resistance.......	60 lb
Total resistance........	100 lb per ton

Tractive force = 600 − 2400 × 0.03 = 528 lb

$$\text{Load} = \frac{528}{100} = 5.28 \text{ ton}$$

10% Grade

Rolling resistance................	40
Grade resistance.................	200
Total resistance.................	240

Tractive force = 600 − 2400 × 0.10 = 360 lb

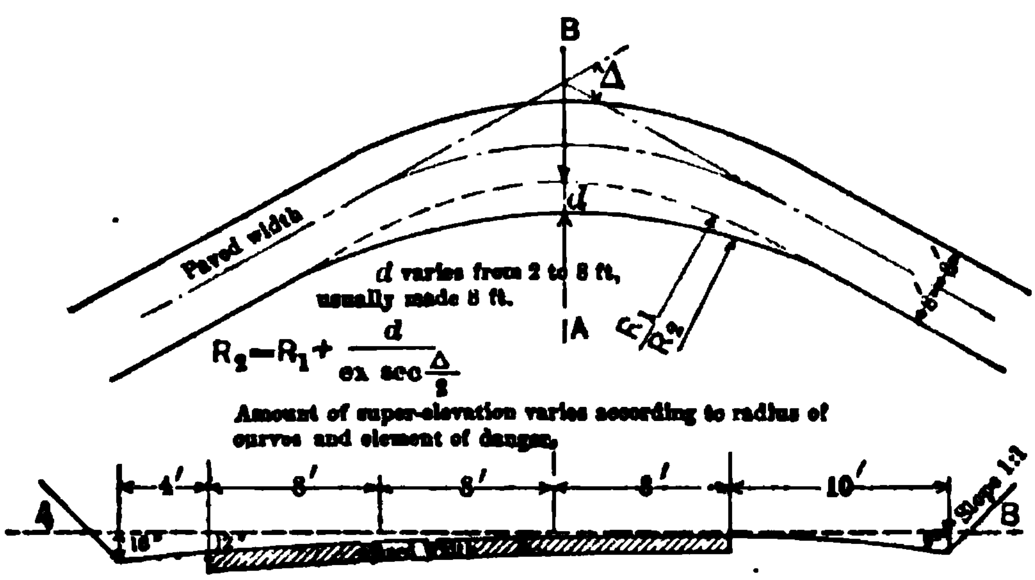
$$\text{Load} = \frac{360}{240} = 1.5 \text{ ton}$$

Maximum Grades. In Prussia the maximum gradients adopted are as follows: In mountainous districts 5%, in hilly country 4%, in flat country 2.5%. In Bavaria, maximum grade in rugged country on state and district roads is 5% and on the communal roads 7%, in the neighborhood of large towns on roads taking heavy traffic 3%. In the north of France and Belgium, in relatively flat countries, 3% is a maximum in constructing new roads, on national roads in mountainous countries 5% is recommended. Many of the states in the United States have made a 5% or a 6% grade the maximum on the main roads of the state system. On roads of lesser importance the maximum limit is increased in some instances to as high as 8%. There will always be exceptional cases where the maximum limit cannot be adhered to and each case will have to be treated in a way to obtain the best grade possible consistent with the conditions encountered.

Minimum Grades. A road might be constructed perfectly level longitudinally, if proper drainage could be obtained at the same time. A slight pitch is usually given to the grade for purposes of drainage, altho level grades for short distances are sometimes used where the road is on an embankment or a good fall can be given to the ditches at the side. As a general rule the smoother the surface, the lower the rate of grade which can be considered the minimum. The following minimum grades for broken stone roads have been used: England 1.25%, France 0.8%, United States 0.5%.

7. Crowns

On tangents the surface of the road slopes downward both ways from the center line. On curves of small radius usually the slope should be made a one-way slope for the full width of roadway. This not only makes a safer roadway for the high speed traffic but also tends to distribute the traffic in passing around the curve so that the wear on the surface is more even. The scheme for widening and sloping the roadway on curves used by the Los Angeles County Highway Comm. is shown in Fig. 7. The following method is used by the Mass. Highway Comm. On curves



SECTION A-B

Fig. 7

over 500 ft radius the amount of crown and its method of distribution is the same as on tangents. On curves under 500 ft radius the slope is made a one way slope between the P. C. and the P. T. The transition from the two way slope on the tangents to the one way slope of the curve is made a gradual one by starting from a point 100 ft beyond the P. C.or P. T. of curve on the tangent where the surface slopes both ways and working to a point 50 ft beyond the P. C. or P. T. where the half width of roadway on the side corresponding to the outside of curve is made level and thence to the P. C. or P. T. where the slope is entirely a one way slope upward from the inside of the curve. The three sections are shown in Fig. 8 for a width of roadway of 20 ft and a transverse slope of ½ in to the ft. For crowns of roadways, see the several Sections on different types of roads and pavements. Typical examples of crowns of shoulders, and of the construction of shoulders as affected by crowns of roadways and side-slopes in excavations and on embankments, are shown in Fig. 9.

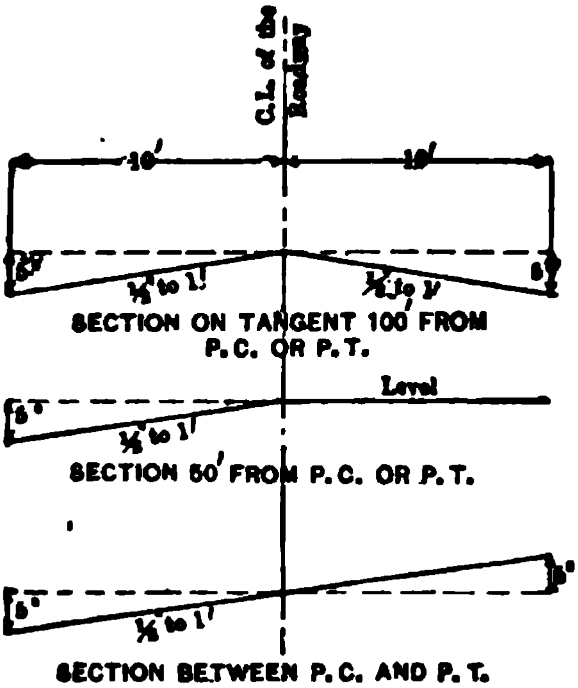


Fig. 8

8. Widths

The width of roads should be determined not only with reference to the present traffic but should be made sufficiently wide to accommodate the traffic of the near future. The function of the road, whether it is one for thru travel or for local travel, will have a direct influence on the width required.

Right-of-Way. The width of right-of-way, as the road approaches a town, should be increased if there is a possibility of the town growing in a direction that will follow the road. For the same reason it is of special importance to provide a wide right-of-way on those roads of the system which form the main thorofares between a city and a neighboring town or surburban area. A 100-ft right-of-way

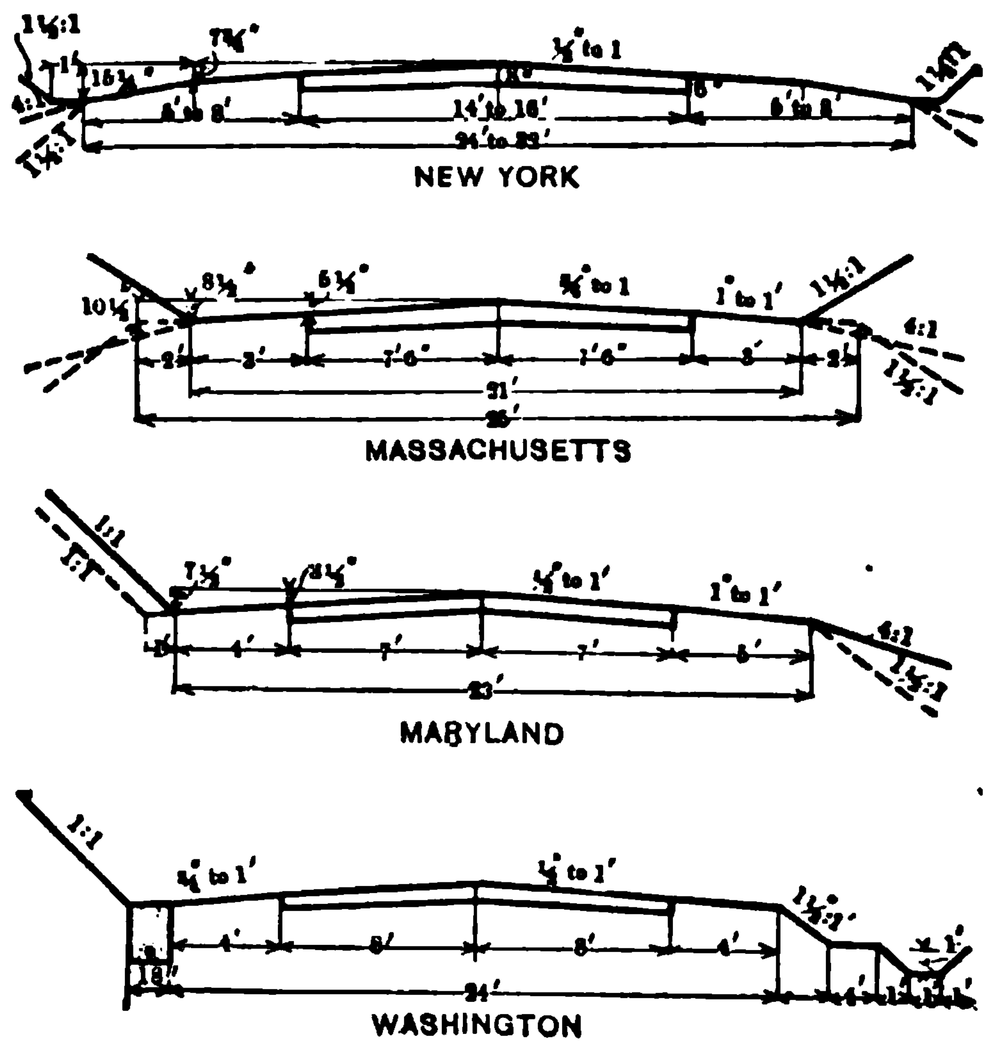


Fig. 9

would be necessary for such roads if at some later time they would become one of the main streets for thru traffic in the city. Great economy will result in making intelligent plans for future expansion at a time when the land values are low and before a district has been built up.

Separate Roadways in Massachusetts (23). "Assuming that the money was available, the question of the practicability of building separate roadways for horse-drawn vehicles, or a roadway on each side of the hardened roadway in the center, on the state highways, depends upon the width of the location and the local conditions.

"Experience has shown conclusively that with the present traffic a hardened roadway of at least 18 ft in width is absolutely necessary on all main roads and a greater width will soon be required. A greater width is necessary on curves and corners, and state highways, where possible, are built with a 3-ft gravel shoulder on each side. The standard width formerly was 15 ft for the old water-bound macadam road, with a 3-ft shoulder on each side. The Commission is reconstructing and widening these roads, as rapidly as funds are available, at a cost of from $6 000 to $10 000 a mile, including the improvement of corners and curves. On some state highways the location is only a little over 30 ft in width. A large majority of the locations, however, are 50 or 60 ft in width, practically all of them since the traffic has increased. On many roads there is a single car track with turnouts; on a few a double track. In a great many places sidewalks are needed.

"It is manifest that where such conditions exist, it would be impossible to have two roadways without very materially widening the location and paying land damages, which in many cases would be very large and in some instances absolutely prohibitive. The widening would also make necessary the cutting of all trees near the roadside, the moving of buildings, etc. With the increase in motor vehicles, the construction of sidewalks, wherever many foot passengers or school children use the road, is more important for the public safety than wider roadways. Taking an ordinary 50-ft location, the sidewalk and grass curb, with trees, would occupy from 8 to 10 ft, the roadway, including shoulders, 24 ft, and the gutter, 8 ft more, a width of 50 ft is used. If there is a car track on one side, 11 to 12 ft more are necessary. If there is a double car track or a turnout, 18 ft is needed for the rails and for 18 in on each side, besides sufficient room, if it is located on the side, to give the required clearance for poles, trees, etc. Consequently, under modern conditions, it is evident that in many cases the locations must be widened before separate roadways could be constructed."

Conclusion Pertaining to Right-of-Way Adopted by 3rd Int. Road Cong. (32). "The main traffic roads should be so designed that spaces are provided for tram tracks, fast and slow traffic, and standing vehicles; and in such a way that they can proceed without unduly intermixing. In fixing building lines along what may ultimately become main roads, regard should be paid to ultimate requirements. Adequate space should be provided between the buildings, and powers for enforcing this should be held by all authorities who decide the widths of roads."

Width of Roadway required will depend upon the amount and character of the traffic. A scheme of providing for occasional passing traffic in narrow roadways is to improve the surface of the earth shoulders with gravel or some other means a few feet each side of the paved portion of the roadway. It should be remembered, however, that on a narrow width of roadway, the wear is greater due to the concentration of the traffic. Therefore, in deciding whether a narrow or a wide roadway is more economical, the increased cost of maintenance should be taken into account. Narrow roadways are usually only adopted where there is a desire to build as much mileage as possible with the money available and the traffic on the road is small in amount and largely of the horse-drawn vehicle type.

Where motor vehicle traffic occurs in any amount, a width of roadway should be provided so that, in passing, the vehicles do not have to run onto the shoulder. Horse-drawn vehicles can pass each other with relatively small clearance since the speed at which they travel is not great enough to do much damage even tho they should graze each other a little and neither would there be danger if the wheels on one side went off onto

the shoulder. For motor vehicles there should be allowed at least 1 ft between the wheels and the outside edge of the roadway and a clearance between two vehicles of at least 1½ ft. The widths of different types of vehicles is as follows: Motor-bus 7 ft 2 in, furniture van 7 ft 6 in, motor car 6 ft 6 in, wagons 5 ft, drays and motor trucks 7 to 8 ft.

Widths Recommended. A width of metalled or paved roadway of 18 ft to 20 ft is recommended for interstate and intrastate highways; for roads of lesser importance, such as those composing the county and town systems, a width of from 14 ft to 16 ft should be used, while in exceptional instances a single track width of 7 to 9 ft may be advisable, provided the shoulders are improved to accommodate passing traffic.

Widths in Use. In Austria the width of roadway on government roads is about 21 ft, on provincial roads 14 to 16 ft, and on district roads from 12 to 20 ft. Many of the important district roads in the north of France have a roadway 20 ft wide, the central 15 ft of which is paved and the remaining 2½ ft on each side is metalled. The metalled roadways of the national roads are 23 ft wide. In England the metalled roadways of the main roads are 16 to 22 ft wide. Standard widths of roadways not including shoulders of state roads in several states of the United States are as follows: New York 14 to 16 ft, Rhode Island 18 ft, Massachusetts 15 to 18 ft, Connecticut 14 to 18 ft, Washington 16 ft, Pennsylvania 14 to 16 ft, Ohio 16 ft, New Jersey 16 ft, Maryland 14 ft. Greater widths than the standard width are built in special cases where the roads pass thru or approach towns.

Location of Car Tracks. The progress and development of communities are dependent to a large extent upon the systems of transportation connecting them with surrounding districts. Street railways and motor-buses are the two systems which must be considered in designing the roads. There are several advantages in having the car tracks located on a part of the highway which is inaccessible to other traffic. This arrangement does not interfere with the convenience of those entering and leaving the cars and has the added advantage that the cars can be operated at higher speeds without danger to the other traffic. The work incident to the maintenance of the track can be carried on without disturbing the surfacing of the roadway. A location within the highway is often more economical for the railway company since the expense of purchasing a right-of-way is saved and the cost of grading is small. From the standpoint of the people using the railway a location within the highway is usually more convenient to their homes. Many interurban electric railways are built on a right-of-way entirely off the highway. Car tracks on roads, which carry four lines of vehicle traffic, might best be placed in the center of the road with a roadway on each side sufficient to take two lines of vehicles. Car tracks which carry two lines of vehicle traffic are placed usually at one side of the road. A design should be adopted which will prevent roadway traffic from using the car track. The following information will be of assistance in studying the problem: Width out-to-out of cars varies from 8 ft to 9 ft 1 in; the clearance between cars passing on a double track varies from a minimum of 5 in to 2 ft. The track gage in the United States is almost universally 4 ft 8½ in.

REGULATIONS AND RESTRICTIONS

9. Boundaries of Roads*

"Boundaries on highways and elsewhere are usually established by persons or municipalities or the government, by descriptions, thru the

*Abstracted from "The Legal Status of Highway Boundaries and Disposal of Surface Waters," by John C. Wait, Better Roads, Aug., 1916.

medium of language, usually written; boundaries, therefore, become a question largely of intention, as expressed or interpreted by the language employed. When the intention is clear, it will prevail, the same as in other instruments, such as deeds, wills, bills, or memoranda of sales, agency and assignment. The INTENTION of the parties, both parties, is what will govern, if that intention be expressed clearly and so that both parties should have comprehended it.

"**Law of Boundaries.** It is when the intention is not clearly expressed that the law asserts itself and applies its principles; giving to the parties the intent, motive and purpose of doing that which is most rational and best for public interests, the security of titles, and the avoidance of litigation and trouble. Such is the basis of our jurisprudence, namely, for the law to assert itself and give to the parties what the courts deem the best policy when they have failed to be precise and certain in the written declarations. With respect to the description of property bounded by streets, roads, and ways, the policy of the law is to give the ways to the abutting owners, subject to the use of such ways for travel and street purposes. That seems to require that abutting owners should own to the center of the road or way.

"**Law of Public Policy.** The law that prevails with respect to boundaries of roads and ways does not exist solely because the abutting owner ever did own to the center of the street, but it is based upon public policy. All American and English courts recognize the existence of a rule or presumption that a conveyance of land bounded on or by a highway passes to the grantee a title to the center of the way. The difference in the opinions by the courts arises from the application of the general rule. The rule is founded upon a policy which tends to guard against inconveniences of the most alarming character. If such a rule were not adopted, confusion would arise and titles would not be secure.

"**Reason for Rule.** The chief reasons for holding that abutting owners shall own to the center of the street or stream, canal, or way are the following:

1. To prevent the existence of innumerable strips or gores of land along the margin or in the beds of streams and highways, the title to which might remain in abeyance for generations, after which, upon the happening of some unexpected event, abutting owners would find themselves harassed with litigation, and would find themselves without the means of entrance and egress from their properties, and surrounded by embarrassments which would result.

2. The abutting owner pays the taxes and is usually assessed for the improvements of the roads and streets, such as paving, curbing, sewers, and it would be an injustice that some one else should reap the benefit of such expenditures.

3. The abutting owner is held responsible for the conditions of the street, such as clearing the walks of snow and all other obstructions.

4. The ordinances, statutes, and courts universally hold abutting owners responsible for all burdens and improvements to his half of the street, which is a good and sound reason why he should have the proprietary interest in it.

"**Effect of Contrary Rule.** Any contrary rule would introduce a flood of unprofitable litigation to abutting owners, unless indeed all roads and highways should be taken over by the State, which would have exclusive ownership in them, but would the State assume the burden of all the improvements necessary to be made in streets, would the State get the requisite benefit from a sidewalk in front of an abutting owner, that it would be willing to pay for such an improvement? Until the State will assume such burdens or assume to provide ways and means for assessemnt of public improvements against the properties benefited, it would seem that public policy would require that the laws should remain as they are and that abutting owners should own to the center of the ways.

"**Application of Rule.** With this presumption in mind, and land bounded by the

words on, by, along, or upon a public way or road, extends to the center of the way, unless there are words in the description to show contrary intent, and the description must be clear and unequivocal that it was the intention of the grantor to limit the landowner to the edge or side of the street. When land is described as lying on a street or along the street, or by the street, or by said road, or when city lots have been described as abutting on a street and designated by numbers, in each instance the courts have ruled that the description extended to the center of the street or way.

"**Abandoned Streets.** After what has been said as to the ownership of abutting owners in streets and ways, it would naturally follow that when streets are abandoned, or even ways such as railways and canals, the land would revert to the abutting owners, and each would take to the middle of the way. This rule prevails generally thruout the States, and when canals or roads are abandoned by the State or by the municipality, and the rights of the public to travel over such ways ends, then, of course, the property with all its rights reverts to the owners thereof.

"**Property in Ways.** A proper understanding of boundaries on highways, or surface waters in connection with them, can be had only by a clear comprehension of the rights, title, and interest of abutting owners and the public or the State or county in such highways. Thruout the New England and Middle States, the ownership of highways and roads is almost universally in the abutting owners, and the public, the State, or the county enjoy only an easement of travel or right-of-way over such lands. The soil, any minerals, water, oil, or gas, all trees and vegetation that abound in or upon said land, belong to the abutting owners, together with the fruit, vegetables or seeds that may grow upon them. Some cases have gone so far as to grant abutting owners the right to remove people from occupying a roadway or highway for other purposes than that of travel, as for sight-seeing purposes, for purposes of trade or observation.

"Road Materials. This question of the ownership of highways frequently arises with the State Department of Highways when materials, as gravel and sand, are taken from banks in the highway for repairs or construction purposes at other points than where taken from. Abutting owners have been known to come forward with their teams and to forbid the State or its contractors taking such gravel, sand, or rock, and to themselves load their wagons and to appropriate such materials to their own individual purposes. Generally speaking, where the public or the State or county has only an easement of travel or right-of-way, the abutting owner may prevent the removal of such materials or may take them himself to his own uses and purposes, whether for filling or otherwise, and the State may not appropriate them for repairs to other portions of the driveway or road. In some States and jurisdictions this has been permitted and held to be lawful, and in others it has been forbidden, where abutting property-owners have objected or protested.

"Highway Specifications. In the preparation of specifications, the highway engineer may not, in the name of the State or county, give to the contractor the use of gravel and sand from the road-bed, nor authorize the contractor to appropriate such materials. Abutting owners may prevent such acts in many States and jurisdictions. It is usually wiser to state in the advertisement or invitation to bidders that appropriate and suitable materials are to be had along the line of the work, but that the contractor must make his own arrangements for the purchase from abutting or near-by owners of their materials of construction, and that the State assumes no liability in the matter. In preparing specifications for road-building, the most material factor is the use of the materials at hand. Yet frequently the government may not avail itself of the materials of construction found within the road-bed or right-of-way. This situation is going to have considerable bearing upon the future of our country and in the problem of preparedness or defense, for good roads and ways are the most vital element of modern warfare. If the State cannot control, dispose of or even own the materials that occupy the roadway, it is high time that thorofares were established thruout

the country by the condemnation of lands over which they pass and the exclusive ownership of such thorofares by the State or the Federal Government.

" Uses of Highway Restricted. In the present situation, where the abutting owner and usually a farmer owns the right-of-way, it is doubtful even if the use of the right-of-way for contractor's plant and material is within the easement owned by the public. And the subject of the ownership of streets and roads is closely identified with the obstruction, interference with travel and the rights-of-way over roads and highways.

" Husbandry in Road. With the ownership of the land in the abutting owner goes the right to pasturage of cattle, swine, and other domestic stock; also the plowing and planting of such rights-of-way, not used for travel, for potatoes, corn, and other crops. While this is not usual, for the reason that the farmer's crops would doubtless suffer from the public employing the road for travel and for driving droves of stock, horses, cattle, sheep, etc, which would trample down the potatoes, eat up or destroy the corn and other crops, yet if the abutting farmer cares to assume that risk and his cultivation of part of the right-of-way does not interfere with travel, he undoubtedly may do so. It is a prevailing custom in some parts of the country to plant apple trees along the roads, and to gather the hay crop and to pasture the horses in the roadway, and these acts, while they may appear ordinarily to the layman or even to the engineer as acts of lawlessness, are on the contrary acts strictly within the rights of abutting owners.

" **Boundaries Established.** Boundaries may be established by other means than by deeds or wills or by the property-owners' own voluntary act; as, by the legislature, by court proceedings, by arbitration, or by acquiescence or long usage. When the legislature or court fixes boundaries, they are more likely to be definite and certain than when described by individuals. If they are not, then the same rules of construction are applied to them by the courts as in the case of individuals; except, however, that the court will protect the interest of the State as against the individual.

" Arbitration. Disputes as to boundaries may be submitted to arbitration and the parties bound by an award, the same as in other controversies. In such a case the courts would be bound to sustain such an award.

"Adverse User. Boundaries may be also fixed and determined by adverse user or prescription. If the public or a party use a piece of land or a way over or thru land in a certain way or for certain purposes, they will, after long usage, usually 21 years, acquire a right to continue to use the land or way, in spite of the owner's objections. Such rights are termed adverse or prescriptive rights. In such cases the boundaries are restricted to the land actually occupied or used, for the full period, usually 21 years.

" User Adverse the State. Adverse use or possession can not be had against the State or government; so that persons and the public cannot deprive the State from asserting at any time its rights in property, unless by special act of legislature such rights are given to the public or to abutting land-owners.

" Conflict of Calls in Descriptions. When there is conflict in the calls of a description, the same rules apply as to boundaries between adjacent owners. One general rule is that the most certain and definite call or description shall prevail, as best showing the intention of the parties. Thus, a permanent monument would prevail over courses and distances; and the course is held to govern the distance, tho why it should is not clear; and courses and distances control acreage."

10. Surface Waters*

" **Defined.** Surface waters have been defined as waters on the surface of the ground which are of a casual or vagrant character, following no definite course and having no substantial or permanent existence, and which are lost by being diffused over the surface of the ground, thru it by percolation into the soil or from it by evaporation. They are dis-

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* Abstracted from " The Legal Status of Highway Boundaries and Disposal of Surface Waters," by John C. Wait, Better Roads, Aug., 1916.

tinguished from watercourses, which flow in definite channels, and from lakes and ponds, which have a substantial, as distinguished from a vagrant existence. When surface waters enter a stream or permanent lake or pond, they lose their character as surface waters, and the rights of persons in their use or diversion are governed then by the law of watercourses and of lakes and ponds. Flood waters caused by the overflowing of the banks of watercourses are usually treated as surface waters until they return to the stream when the water subsides.

"**Civil and Common Law.** The law applicable to surface waters is not general thruout the United States, but is considerably different in the several states and in adjoining states, and two rules have been adopted, one known as the rule of the CIVIL LAW and the other the rule of the COMMON LAW, and some states have adopted a modified doctrine which embodies essential principles of both rules. The Southern States and some of the Middle States have adopted the civil law rule, which is, generally speaking, the right of the owner of the superior or higher lands to drainage upon the lower lands, this being based upon the natural law of water to seek its own level; and the reason for its adoption is that a rule which natural rules enforce is unquestionably and clearly the better and more equitable law, because there can be no surprises or hardships in this, for each successive owner takes his land with whatever advantages or inconveniences nature has stamped upon it.

"CIVIL LAW. Under the civil law, therefore, a servient owner of lands at a lower level could not obstruct the flow of waters from land at a higher level, and if the servient owner desires to improve his land, he must make provision by drains or otherwise for the discharge of natural flow of surface waters from the higher or upper lands, and he must do this or obstruct them at his peril.

"COMMON LAW. Under the common law rule, which prevails in the Northern and Eastern States and in some of the Western States, a servient landowner has the right to take any measures necessary to the protection of his property even tho he prevents the entrance upon his land of waters which naturally flow there, and if damages result to the upland owner they afford no cause of action. The servient owner may build walls, embankments, and dams, and protect his property by levees or otherwise from the overflow from his neighbor, under the common law rule, tho he may not do so by trespassing upon the land of his neighbor.

"**Care of Waters.** The care, diversion, or obstruction of surface waters in the construction and maintenance of highways, as stated before, is a serious problem. It is not always convenient to divert the waters from a highway at their natural point. If so diverted, they frequently will require ditches or drains upon adjoining property, which cannot be built except with the consent of the adjoining owner or by condemnation proceedings; or, if such ditches or drains be not provided, the waters may be deflected back into the road at some lower point. If a road be upon a side hill, surface waters will accumulate on the upper side of the road, and after being conducted some distance must be carried either over or under the roadway to the lower side, and there be discharged in considerable quantity either into the gutter upon the lower side or upon the abutting landowner. Waters so conducted and collected will in heavy storms be projected upon abutting landowners in large quantities, and will ordinarily carry silt, sand, gravel, and stones of considerable size, piling and heaping up to the detriment of the abutting landowner and over considerable area;

sometimes approaching a quarter-acre. Usually such a diversion and projection of sand and silt upon an abutting landowner bring a protest and sometimes claims against the State or county. In sparsely settled counties, where land is not of much value, the question would not be material, but in localities where land is valuable, or where it is used for manufacturing, residential, or even gardening purposes, the trespass becomes a serious one, and it is equally serious for the State to undertake to conduct waters for any considerable distance down a steep hill within the highway boundaries.

"Devices. This problem was formerly met by placing frequent water bars across the roadway. The advent of the automobile and of high-speed vehicles has practically done away with the water bar, and the State has now to provide adequate gutter ditches and drainage for such distances along the highway as will reach an accommodating abutting landowner or some watercourse into which the water may be discharged. These conditions sometimes necessitate the construction of pipe drains and in some instances of brick culverts of considerable length and expense, for it is unquestionably the law that the State or county, in the construction of its highways, may not accumulate surface waters by gutters, ditches, trenches, or otherwise, and discharge the water in a body upon abutting owners, to their damage and detriment, any more than the owner himself may collect quantities of water in trenches or drains and discharge it into the highway to its detriment and destruction.

"Discharge Waters. As to what would be an unreasonable discharge of water in either direction would depend probably upon the results or consequences. If the water were dissipated over a considerable area, so as to flow away in the bushes or grass, and without casting débris upon the abutting owner, thus minimizing the damages which he might suffer, it would probably be within the province of the highway engineer to so divert surface waters, and the liability of the State or county for such acts would depend largely upon the injury or damage that resulted.

"Personal Liability. The personal liability of a public official, as a highway superintendent or commissioner, for such diversion would depend upon whether he acted in good faith and as a prudent man in the discharge of his duties. If it were done outside of his duties and in a reckless manner, his liability might be established.

"Ownership of Abutters. In connection with the diversion or casting of waters into the highway by an abutting landowner, it should be remembered that the land of the ordinary and usual highway, outside of municipalities, belongs to the abutting owner, and that the State, county, or public have only the right of travel in it, and those rights which are necessary to maintain the highway and to make it safe for travel. It would, therefore, follow that an abutting landowner would be given every privilege and permission in the use of an abutting highway that he would have in his own land, so long as it did not interfere with public travel and the public uses of the highway for travel. Originally, the uses of highways were solely those of travel, but by statute and by judicial legislation highways have in many instances been burdened by other uses, such as drains, requisite and necessary to properly carry off the waters from the highway; also in some instances telegraph and telephone poles, sewers, and even waterpipes. These later uses, however, have been largely confined to villages and cities, where the comforts and conveniences and protection of its inhabitants would seem to require a household supply of water, gas, electricity, and electric communication, and likewise sewers to carry away the wastes.

"Natural Drainage. Surface waters may, of course, be drained into natural or even artificial watercourses, if the artificial watercourses are conducted to natural ones, as watercourses are outlets provided by nature for carrying off such waters, and the law pertaining to watercourses, forbids their obstructing, damming, or interference with to the detriment of abutting or neighboring landowners. Generally speaking, the drainage of highways is governed by the same rules as farm drainage, and surface waters of such highways can be collected and discharged into watercourses even tho the volume of said watercourses is greatly increased.

"Licenses. A highway commissioner, on behalf of the State, may, of course, secure by contract the right to divert the natural flow of surface waters upon land and to discharge them upon or over the land of abutting owners, or to maintain artificial

drains over such lands. In making such contracts or agreements with farmers, the engineer or commissioner should be careful not to obligate the State by contract to the maintenance and repair of such drains or to make them liable for the damming or obstruction of such drains or ditches. A contract which would bind the State would ordinarily be required to be made by some higher official than engineer in charge of construction, or even a highway commissioner, unless he were given authority expressly by statute.

"Condemnation. If such an agreement cannot be made with the abutting owner, provision is then usually made by which the commissioner of highways, or some other designated county or state official, may proceed to condemn a right over lands for such a drain or ditch.

"Filling. Low places, as in marshes or ponds or covered with surface water, may be filled in and raised by a commissioner or engineer in the same manner that any adjoining owner may fill in low places of his land and make it arable or useful. No complaint or action for injuries or damages may be had by adjoining or abutting owners by reason of the increase in depth of surface water over their lands, for the State or county may improve its land for the purposes of a highway, as for travel, as landowners may improve their premises for farming or manufacturing purposes.

"Damages from Waters. There are several conditions that arise from surface water which may prove a source of injury and damage, resulting in claims against the person who directs, diverts, and discharges the surface waters in an unlawful manner. These are known as obstruction, diversion, repulsion, discharge, impounding, polluting, and fouling of waters. There are the direct discharge of waters against the property or land of another, the setting back of waters and consequent overflow of lands and structures, the impounding of waters by damming, as by embankments, and the sudden escape of those waters by washouts or the failure of the embankment; then there are the withdrawal and appropriation of surface waters, which the lower owner may be entitled to have flow in their natural course."

11. Traffic Regulations

General Considerations. Since 1910 especial attention has been given to traffic regulations covering all phases of the use of public highways by horse-drawn and motor vehicles.

The safe and expeditious use by vehicles of municipal streets has been given thoro consideration with the result that many cities now have satisfactory traffic rules. See Sect. 7. Similar regulations have been adopted by some states, those of New York, passed by the 1917 Legislature, being a notable example.

Regulations pertaining to allowable weights, speeds and dimensions of vehicles, in order to be placed upon equitable basis, should be adopted only after extensive investigations by experts. Certain statistical data and typical state laws of value in connection with a consideration of such regulations are cited:

Motor-Truck Dimensions as given by Masury (24). "OVERALL HEIGHT. The overall height of present motor-trucks seldom exceeds 12 ft. The height is limited by the headroom necessary to drive under such structures as railroad bridges at grade crossings, enclosed or top bridges, elevated railroad structures, overhead trolley wires, doorways of buildings, ferry boats. Railroad grade crossings seldom provide less than 12 ft headroom. Enclosed top bridges do not always provide as much as 14 ft clearance.

"OVERALL WIDTH. The overall widths of present motor-trucks are in very few instances in excess of 96 in. This dimension is limited by the distance between parts of such structures thru which vehicles must be driven, as doorways, elevators in buildings, ferry boats. Overall widths are to a great extent controlled by conditions that minimize the clearances between passing vehicles and the clearances between passing vehicles and stationary objects, as posts, trees, poles, elevated railroad pillars, curbs, etc, and that make negotiation both difficult and dangerous.

"OVERALL LENGTHS. The material to be transported is the most important factor

controlling length. Overall lengths of existing motor-trucks seldom exceed 24 ft. Overall lengths of tractors and semi-trailers seldom exceed 35 ft. Ladder wagons for fire department use sometimes attain lengths of 40 to 45 ft. Structural steel girders, telegraph poles, timbers and similar materials sometimes in excess of 60 ft are transported by tractors and semi-trailers. Tractor and trailer trains have attained lengths of over 80 ft, but are difficult to handle because the trailers cut under on turns. Lengths are also controlled and restricted by the difficulties encountered in negotiating turns, particularly where roads are narrow and cross at acute angles, and stationary objects, as posts, poles, pillars, trees, etc, are located in close proximity to the sides of the roads. It is, of course, obvious that wheelbase length is the most important factor that determines the turning radius of motor vehicles, and that the radius increases as the length increases.

"Vehicles of maximum dimensions as follows have been either projected, designed or built, and are in few instances extreme, the figures serve to show simply a few conditions: Five and one-half ton tractor-trailer for transportation of milk; width, 90⅝ in; height, 11 ft; length, 321¼ in. Truck equipped with body to carry timbers 85 ft long. Six and one-half ton, 180½-in wheelbase truck, designed with racks to carry steel; width, 96 in. Two-ton, 10-ft wheelbase truck, designed with special semi-trailer of 20-ft wheel base, to transport aeroplane 30 ft long. Seven and one-half ton tractor, designed with special semi-trailer, which carries a tank of 15 tons capacity; height, 10 ft 6 in; length, 26 ft 9 in."

Motor-Truck Traffic on New York Highways (18b). "It was found that the trucks and buses range from 1 ton to 15 tons in weight, including the vehicle. By far the largest number consist of 3-ton trucks. The reports obtained as to each truck and bus upon an estimated yearly period of 40 weeks, eliminating the entire 12 weeks during the winter season, show that the traffic upon improved state and county highways from motor-buses and motor-trucks amounts to 14 734 680 miles for the 40 weeks, having 60 216 520 ton-mileage. The following figures show the mileage and average speed for the various sizes of trucks:

Total Load per Truck in Tons	Total Mileage for the State per Year of 40 Weeks	Average Speed Miles per Hour
1	565 680	19.4
1½	858 720	17.4
2	1 609 680	17.1
2½	1 520 080	17.7
3	2 217 880	16.5
3½	1 039 920	14.6
4	1 803 840	14.6
4½	503 680	14.2
5	1 005 400	13.9
5½	176 760	12.3
6	652 640	13.2
6½	267 880	11.9
7	633 960	13.2
7½	132 880	13.6
8	681 160	12.7
8½	24 400	11.3
9	390 080	12.9
10	529 280	13.2
11	8 880	11.7
11½	8 640	10.0
12	59 320	12.1
13	4 640	10.0
14	4 640	10.0
15	4 640	10.0

Regulation of Horse-Drawn Vehicles by McCormick (25). "While there is wide variation in sizes and types of wagons marketed by the different manufacturers, it is believed that five sizes of wagons will be sufficient to meet all the needs of farming operations and all general work except the heaviest trucking and certain specialized hauling, which is likely to be confined to city pavements. These five sizes are:

1. One-horse wagon having a gross load capacity of 2000 lb and a skein from 2⅛ to 2⅜ in.
2. Light 2-horse wagon with a skein approximately 2½ in, and a gross carrying capacity of 3500 lb.
3. Medium 2-horse wagon with a skein not exceeding 3 in, and designed for a gross load of 4500 lb.
4. Standard 2-horse wagon with a skein of 3¼ in and a gross carrying capacity of 6800 lb.
5. Heavy 2-horse wagon having a skein of 3½ in and gross load capacity of 7500 lb.

"As there is considerable difference in the practice of manufacturers regarding the

size of skein used on the various types of wagons, it is recommended that wagons be not designated by size of skein but according to the gross load capacity, and that a name be adopted for each of the sizes. It is further recommended that the gross carrying capacity of the wagon be shown by stencil or plate on the back of the rear axle. The following widths of tire are recommended for each size of wagon, based on road-roller weights and on results of traction tests conducted by the U. S. O. P. R."

Type of Wagon	Gross Weight Loaded	Width of Tire
	Pounds	Inches
One-horse wagon	2000	2
Light 2-horse wagon	3500	2½
Medium 2-horse wagon	4500	3
Standard 2-horse wagon	6800	3
Heavy 2-horse wagon	7500	5

New York State Traffic Regulations as adopted by the Commissioner of Highways in 1914 are as follows:

"Sec. 1. No traction engine, road engine, hauling engine, trailer, steam roller, automobile truck, motor or other power vehicle shall be operated upon or over State or County Highways of this State, the face of the wheels of which are fitted with flanges, ribs, clamps, cleats, lugs or spikes. This regulation applies to all rings or flanges upon guiding or steering wheels on any such vehicle. In case of traction engines, road engines or hauling engines which are equipped or provided with flanges, ribs, clamps, cleats, rings or lugs, such vehicles shall be permitted to pass over such highways provided that cleats are fastened upon all the wheels of such vehicles, not less than 2½ in wide and not more than 1½ in high, and so placed that not less than two cleats of each wheel shall touch the ground at all times, and the weight shall be the same on all parts of said cleats. The foregoing regulations relating to flanges, ribs, clamps, cleats, rings or lugs shall not apply to traction engines used solely for agricultural purposes, but the following requirements shall apply to such traction engines: The guide band on the front wheels shall not be less than 2 in in width, but no flanges, ribs, clamps, cleats, rings or lugs shall be required upon the front wheels. The full set of cleats upon the rear wheels of the original design as furnished with the engines must be used, and no rivet heads or bolt heads shall project, and the use of such traction engines for agricultural purposes shall not permit the use for hauling purposes, excepting the hauling of threshing and other agricultural equipment necessary for threshing and agricultural purposes. This provision shall in no case relieve the owner of any traction engines from liability for damage to roads from defective wheels. The use also of ice picks or mud lugs shall be strictly prohibited on State and County Highways.

"Sec. 2. No traction engine, trailer, steam roller, automobile truck, motor or other power vehicle shall be operated upon or over the State or County Highways of this State, nor shall any object be moved over or upon any such highways upon wheels, rollers or otherwise, in excess of a total weight of 14 tons, including the vehicle, object or contrivance and load, without first obtaining the permission of the State Commission of Highways as hereinafter provided. No weight in excess of 9 tons shall be carried on any one axle of any such vehicle.

"Sec. 3. The tire of each wheel of a traction engine, road engine, hauling engine, trailer, steam roller, automobile truck, motor or other power vehicle, except traction engines, road engines, and hauling engines, shall be smooth, and the weight of such vehicle, including load, shall not exceed 800 lb upon any inch in width of the tire, wheel, roller or other object, and any weight in excess of 800 lb upon an inch of tire is prohibited unless permission is obtained from the State Commission of Highways as hereinafter provided.

"Sec. 4. No motor or other power vehicle shall be operated upon any State or County Highway of a greater width than 90 in, except traction engines which may have a width of 110 in.

"Sec. 5. No traction engine, road engine, hauling engine, trailer steam roller, automobile truck, motor, or other power vehicle, carrying a weight in excess of 4 tons, including the vehicle, shall be operated upon any State or County Highway of this State at a speed greater than 15 miles an hr; and no such vehicle carrying a weight in excess of 6 tons, including the vehicle, shall be operated upon any such highway at a speed greater than 6 miles an hr when such vehicle is equipped with iron or steel tires, nor greater than 12 miles an hr when the vehicle is equipped with tires of hard rubber or other similar substance.

"Sec. 6. The State Commission of Highways of the State of New York, upon proper application in writing, may grant permission for the moving of heavy vehicles, loads, objects, or structures in excess of a total weight of 14 tons over its State and County Highways upon proper application in writing being made therefor, and under such restrictions as said Commission may prescribe.

"Sec. 7. The owner, driver, operator or mover of any vehicle over any State or County Highway shall be responsible for all damage which said highway may sustain as a result of a violation of any of the provisions of the foregoing Rules and Regulations, and the amount thereof may be recovered in an action of tort by the State Commission of Highways or by any County Superintendent of Highways of any county or by any Town Superintendent of Highways of any town in which said violation occurs.

"Sec. 8. These amended regulations to take effect February 24, 1914.

"Section 24 of Chapter 25 of the Consolidated Laws, entitled 'The Highway Law,' provides that any disobedience of any of the foregoing rules and regulations shall be punishable by a fine of not less than $10, and not more than $100, to be prosecuted by the Town, County or District Superintendent, and paid to the County Treasurer to the credit of the fund for the maintenance of such highways in the town where such fine is collected."

Michigan Traffic Regulations, as passed by the 1917 Legislature, are as follows:

"Sec. 1. It shall be unlawful to operate any vehicle upon the public highways of this State, the gross weight of which exceeds 15 tons.

"Sec. 2. It shall be unlawful to operate any vehicle, except motor-driven vehicles, upon the highways of this State, the gross weight on any wheel of which exceeds that given in the schedule under section 3, this act.

"Sec. 3.

Width of Tire in inches...	1	1½	2	2½	3	3½	4	4½	5
Maximum wheel load in pounds..	400	600	800	1 100	1 400	1 800	2 200	2 700	3 200
Maximum load for 4 wheels.....	1 600	2 400	3 200	4 400	5 600	7 200	8 800	10 800	12 800

"Sec. 4. In case a vehicle is equipped with a braking device said brakes shall be of a friction type and not of a type that will cause a deadlock of the wheels when applied.

"Sec. 5. No motor trucks or trailers, hereafter operating upon the public highways of the State, shall have a gauge of more than 75 in measured from center of tire to center of tire, and shall not be more than 96 in wide over all nor over 12 ft 6 in in height.

"Sec. 6. No motor trucks or trailers, hereafter operating upon the public highways of this State, shall be equipped with driving wheels the tires of which are of metal that may come in contact with the surface of the road, or which have a partial contact of the metal with the surface of the road, except where chains or other non-skidding devices are used: Provided, that motor trucks or trailers may be used on any road or highway which are not part of the State reward system: Provided, that should any improved highway be damaged by the use of chains or other non-skidding devices, the person, company or corporation owning or operating such vehicle, shall be liable to arrest and penalties as hereinafter provided.

"SEC. 7. All motor trucks or trailers, now operating or hereafter placed in operation, upon the public highways of this State, shall have placed upon them information relative to their height of wheel, width of tire, gauge, width overall, weight and carrying capacity. This information shall be conspicuously placed upon the vehicle.

"SEC. 8. On the rear axle three-quarters of the gross weight of a motor truck or trailer, and its respective carrying capacity, must be within the limits of the schedule of the respective diameters of wheel, size of tire, and speed per mile, as shown in the schedule under section 14, this act: Provided, that trailers having two wheels, at least three-quarters of the gross weight of the trailer and its respective load shall be upon the axle of the trailer.

"SEC. 9. The front axle shall carry the remainder of the weight of a motor truck or trailer and load combined, and must be within the limits of the schedule of the respective diameter of wheel, size of tire and speed per mile, as shown in the schedule for single tires, under section 14, this act.

"SEC. 10. This act shall apply to motor trucks or trailers used as buses for carrying passengers.

"SEC. 11. This act shall not apply to farm implements or machinery used in road construction.

"SEC. 12. The size of tire and height of wheel shall be taken as that size printed upon a tire by the manufacturer.

"SEC. 13. When a truck is hauling a trailer, the speed shall be governed by the vehicle having the lowest mile per hour rating.

"SEC. 14.

Schedule for the Regulation of Motor Trucks and Trailers Upon the Highway

TABLE FOR A WHEEL OF 32 IN DIAMETER

Size of Tire in Inches	Single Tire		Double Tire	
	Maximum Wheel Load in Pounds	Miles per Hour	Maximum Wheel Load in Pounds	Miles per Hour
2	700	20	1400	18
2½	900	20	1800	18
3	1200	20	2400	18
3½	1600	20	3200	16
4	1900	18	3800	14
5	2200	16	4400	13
6	2700	14	5400	12
7	3200	12	6400	10

For a 34-in wheel, multiply the above maximum wheel load figures by 1.1.
For a 36-in wheel, multiply the above maximum wheel load figures by 1.2.
For a 38-in wheel, multiply the above maximum wheel load figures by 1.3.
For a 40-in wheel, multiply the above maximum wheel load figures by 1.4.
For a 42-in wheel, multiply the above maximum wheel load figures by 1.5.
For a 44-in wheel, multiply the above maximum wheel load figures by 1.6.

"SEC. 15. Whenever by reason of the thawing of frost, or rains, the roads are in soft condition, the maximum carrying capacity of tires on all vehicles shall be limited to one-half the carrying capacity of tires as provided in this act.

"SEC. 16. Any person, firm or corporation which moves, or causes to be moved any vehicle over or along the public highways contrary to the provisions of this act, shall be guilty of a misdemeanor and upon conviction thereof before a justice of the peace or other court having competent jurisdiction, shall be subject, for each offense, to a fine of not less than $5 nor more than $50, or imprisonment in the county jail for not to exceed 30 days, or both such fine and imprisonment at the discretion of the court: Provided, that the provisions of this act shall not apply to the moving

of any vehicle, for which a permit has been granted by the highway officials having jurisdiction. Any permit so given shall state all conditions thereto, shall be in writing, and shall have effect not longer than 30 days from the date when issued.

"SEC. 17. It shall be the duty of the sheriff of each county to cause to be made as his deputies all county, district and township highway commissioners, and others where necessary, and these deputies shall have power to arrest on sight or upon a warrant any person having violated any provisions of this act. Any such deputy who shall wilfully disregard enforcing the provisions of this act shall be guilty of neglect of duty.

"SEC. 18. This act shall not apply to public highways in cities or villages, except as to State rewarded roads."

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SECTION 7

PLANNING OF STREETS AND STREET SYSTEMS

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THE COMPREHENSIVE PLAN

1. The General Plan of the City or Town

Four Fundamental Features. The general plan of a city or town consists of a number of elements each of which is essential to its orderly growth and prosperity. Some writers have enumerated four or five such elements, while others have expanded the list to a dozen or more. The convenience and attractiveness of a town will depend upon four features of its plan, namely:

1. The transportation facilities or the means provided for getting in and

out and for quick movement of passengers and freight from one part of the town to another.

2. The street system in and thru which the daily business is done and by which the people gain access to their homes and pass from these homes to their work, recreation and amusement.

3. The park and recreation facilities upon which the comfort and health of the community are to a large degree dependent.

4. The location of public buildings which may render the conduct of public business convenient or difficult and may give a favorable or unfavorable impression to visitors.

While there are many more elements which go to make up the complex organism called the modern city, those enumerated are the ones that make the greatest impression upon visitors, and of these the most vitally important is probably the street system. Transportation facilities into and out of the city can be improved and extended but a large part of the transportation will always be in the streets themselves and its adequacy and efficiency will be largely determined by the location and dimensions of the streets in which the intra-urban transit lines are located. A park system can be most economically and satisfactorily established in advance of other improvements and the lack of proper parks can be supplied tho the cost be great, but facility of access to the parks and proper connections between the different park units will depend upon an adequate and intelligent street system. Public buildings, like other business buildings, can be changed in location as necessity and convenience may require, but the suitability of their sites, whether they are convenient and commanding or awkward and unprepossessing, will depend upon the streets about them and leading to them. A street system, once adopted and developed, must remain indefinitely. While some streets may be widened and an occasional new street may be cut thru existing improvements, the general street plan, once established and constructed, is fastened upon the town as long as the town itself lasts. A catastrophe, such as the great fire of London in 1666 or the San Francisco fire in 1906, may afford an opportunity for a recasting of the plan for a considerable area, but the desire to rebuild and make a new start is usually so keen that the opportunity is not availed of.

New Cities and Towns. It occasionally happens that a town is laid out in a comprehensive manner at the beginning, on a site which is topographically adapted to the development of a stately and convenient city, as was Washington more than a century ago, and as is proposed in the case of the new Australian capital. Sometimes an industrial city is planned and built upon an entirely new site where transportation facilities for the supply of raw material and the shipment of manufactured products are more important than picturesque topography. A national capital is usually planned on a scale which will be far beyond the resources of the ordinary city, and the industrial town is designed for a particular kind of manufacturing and a special class of inhabitants.

The Evolution of a Large City. Most great cities pass successively thru the stages of village, town and small cities, and their highway systems, starting with the village green and the streets surrounding it, are gradually extended to meet traffic needs as they develop. Even when a city has attained considerable size and commercial importance, additional areas are from time to time added to it and the streets of the older town are commonly extended into the new portions and connected in some fashion with those which may have been established by private developers. While

the need of a more convenient system of main thorofares to furnish quick and easy connections between different parts of the town may become apparent and some of them may have been created at large cost, the new additions are seldom planned with the view of avoiding old mistakes, or providing continuous thorofares which will connect with those which have already been established in the old town, or which it is quite obvious will have to be created in the future, or which will furnish adequate connections with nearby towns, or which will take account of the probable requirements of the future. In other words, the street system is too frequently designed to meet simply the actual needs of to-day and takes little account of future expansion and increase of traffic.

2. The Influence of Topography

The Topography of the Site should be the first thing to be considered in determining the general features of the comprehensive plan. Upon it will especially depend the system of main drainage, provision for which must be kept in mind from the beginning, and the transportation system which, while it will naturally be designed to carry people where they want to go, should be able to follow the lines of least resistance, excessive grades and sharp curves involving not only heavy operating expenses but a certain amount of danger. A street plan which is prepared in the office without sufficient information as to the topography of the ground upon which it is to be laid out may look very well on paper, but is likely to be found entirely unsuited to actual conditions and, if persisted in, may impose a heavy initial burden for the construction of the streets and a perpetual handicap upon traffic by reason of unnecessarily heavy grades. The first step, therefore, is to secure a good topographic survey of the territory to be platted. It need not cover the entire area in great detail; such surveys are expensive and the work of planning the street system should not be loaded up with needless cost at the start.

The Topographic Survey required for the initial plan should show existing roads with the location of the buildings fronting on them, the natural drainage including both the valleys and the ridges dividing the drainage areas, the existing railroads and routes suitable for additional lines, the water front if there is one and the localities best adapted for the accommodation of water-borne commerce, and the places which, from their picturesque features, are most suitable for park reservations. Further topographic details are not required for the first study of the street plan; they will come later. A contour map or a model will be of great help in laying out the first skeleton plan. When this has been pretty well settled and the time comes to fill in the details, further surveys will be necessary, but they can be taken up one section at a time as each of the areas lying between the arterial streets can and should be studied separately. In these again proper drainage should be the first consideration, while the location of property lines will be of great assistance in so planning the minor streets as to avoid damage caused by leaving unusable remnants wherever it is possible to do so and still secure a rational and convenient plan.

Avoidance of Heavy Grades and Grading. The initial step in the physical creation of a street system is the grading and, as this comes at a time when the value of the abutting property is small, the cost should be kept down to the lowest figure consistent with a reasonable plan. The preference for rectangular blocks which will produce the greatest possible number of right-angled lots of conventional size is quite general, and excessive grading

or needlessly steep grades are frequently the price paid to secure them. This policy often defeats its own purpose, as the grading up or down of the abutting lots is likely to involve a cost greater than the value of the few lots gained by a rectangular system over those which would result from one conforming more closely with the natural surface, while the latter would be far more attractive. There is something of a reaction against the rigid rectangular plan, evidenced by the introduction of curves and deflections even where there is no obvious reason for them. A long, sweeping curve may be a pleasing feature of a street plan on level ground; diagonal streets to afford direct access from one part of the tract to another are always desirable; but a series of sharp curves and frequent abrupt changes of direction are as inappropriate for a level site as are straight lines regardless of natural contours for a rugged site.

Location of Public Buildings. Even in the first study of the general plan the location of public buildings should be given consideration, and such location should depend upon the arterial street system, as they should be easy of access from the main lines of travel and transit, and upon the general topography as they should, if possible, be so placed that they can

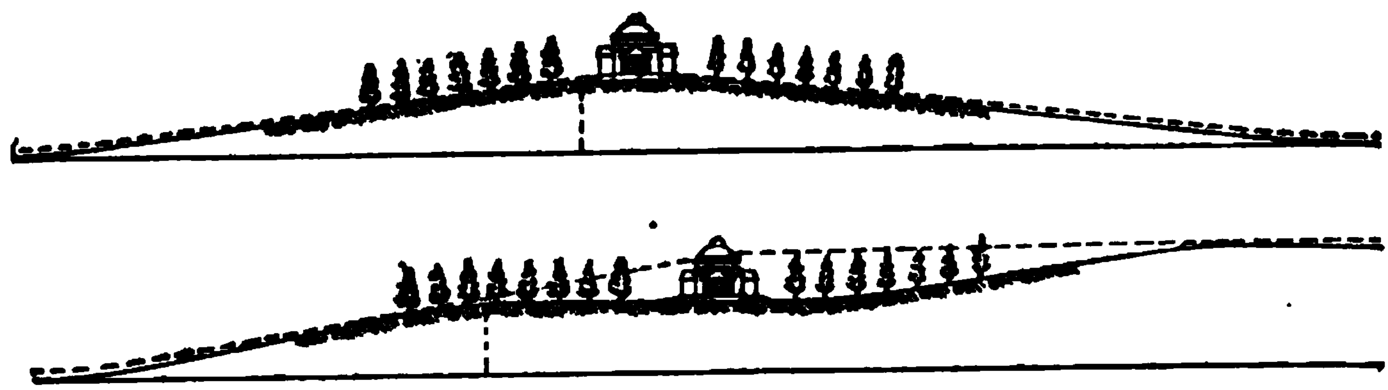

Fig. 1. Illustrating the Proper and Improper Location of an Important Building with Respect to the Grades of the Streets Approaching It

be seen to advantage. Grade summits are the most appropriate locations, enabling them to be seen as they are approached from any direction. The advantage of such a location with respect to grade is shown by the two examples given in Fig. 1.

Precipitous Hillsides or Deep Ravines may exist in the area to be platted, and, while these are of little value for development as real estate, they will make admirable parks. Such places should be located in the topographic survey, and the main traffic highways should be so fixed as to afford easy access to them when they become public pleasure grounds.

Adaptation of Plan to Topography. The general plan should be adapted to the topography. Attempts to create on a level plain a city having the picturesque features of a hillside town will result in failure, while to lay out on a rugged site a plan suited to a level or gently sloping tract will not only involve needless expense but will sacrifice opportunities for charming effects and produce a result which is palpably commonplace.

3. The Arterial Street System

The Traffic Thorofares, while their position cannot be predicted with certainty, will be likely to follow the old roads which have served, many of them for generations, to connect the main centers of population. Such roads usually follow lines of least resistance. The development both of business and residential property is most likely to take place in and about

these already established centers and to extend outwards from them. Traffic will, therefore, increase along these connecting roads which will become the main streets of the greater town. The old highways will probably have been ordinary country roads, some two, some three, and in exceptional cases, four rods wide; but in few, if any, cases of sufficient capacity to meet future needs. While fairly direct there will be irregularities in their alignment which should be corrected. This can usually be accomplished without leaving any part of the old roads outside of the boundaries of the new streets which always results in difficult problems of title adjustment in order to extinguish the old easements and give the abutting owners proper street frontage.

By widening alternately on one side and the other an 80-ft street can be so laid out as to leave a 50-ft road wholly within its limits and at the same time reduce the curvature and the deflection angles to a degree consistent with the future importance of the new street (see Fig. 2). There will be cases where this is impossible and the old road must be ignored for short distances.

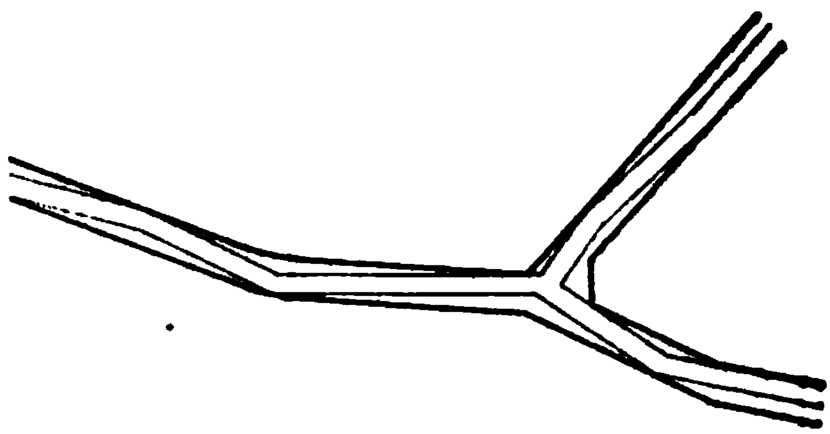

Fig. 2. Showing How Existing Narrow and Crooked Roads can be Included within the Lines of New Streets

Connecting Streets. Having fixed the lines of the main streets which are to take the place of the old highways, it will be apparent that other connections will be needed; short cuts between strategic points, intermediate streets to relieve congestion, the joining up of fragments in order to establish direct routes from any one part of the town to any other part, and connections between important streets in the older parts of the town and the main system now being planned.

Parkways. The thorofares thus far considered are those which are to meet the business needs of the city. Some of them may also become routes for pleasure travel, but it is desirable to separate these two classes of traffic as much as possible, and any city which creates a park system should also provide a system of boulevards or parkways to connect them with each other and with the important highways leading out of the city. Kansas City has created an admirable system of such parkways, the entire city being divided into eight park districts each of which has paid by special taxes or assessments the cost of the parks and parkways within its limits (see Fig. 3). These parkways should be of sufficient width to permit the introduction of some parking or ornamental features so that the road from one park to another will be obvious even to those unfamiliar with the general street plan of the city.

Areas Between Main Streets. When the arterial streets shall have been laid out it will be found that they do not form a system of parallel highways and that they do not connect with each other at right angles. This should not be a matter of concern. A rectangular system of main thorofares is the most inconvenient that can be devised, increasing distances and sacrificing directness with no compensating advantages except the creation of right-angled corners for buildings, and even these can be provided to a certain degree by the treatment of important junctions. The

streets thus laid out will divide the territory to be platted into a number of more or less irregular areas, some triangular, some approximately rectangular, and others with five or more sides of varying length (see Fig. 4).

Fig. 3. System of Parks and Parkways of Kansas City

Consideration of their treatment may be deferred until the main street system is fully determined. The lines of the main system should not be controlled by the shape and size of these areas, nor does it matter if they are so located that each must be treated independently of the other. Such independent treatment will, in fact, add interest to the general plan.

Permanence of Traffic Thorofares. Having decided upon the main traffic lines, steps should be taken to insure their permanence in order that the entire plan may not be wrecked by the erection of buildings along the lines of the old roads to such an extent that the cost of widening them will become prohibitive. Most of the older buildings will have been set back sufficiently to permit such widening without building damage, but as the roads gradually assume the character of city streets and the abutting property is subdivided into lots, the tendency is to erect buildings as near the line as possible. The important thing, therefore, is to secure title to the full width of the streets as soon as possible and while values are small.

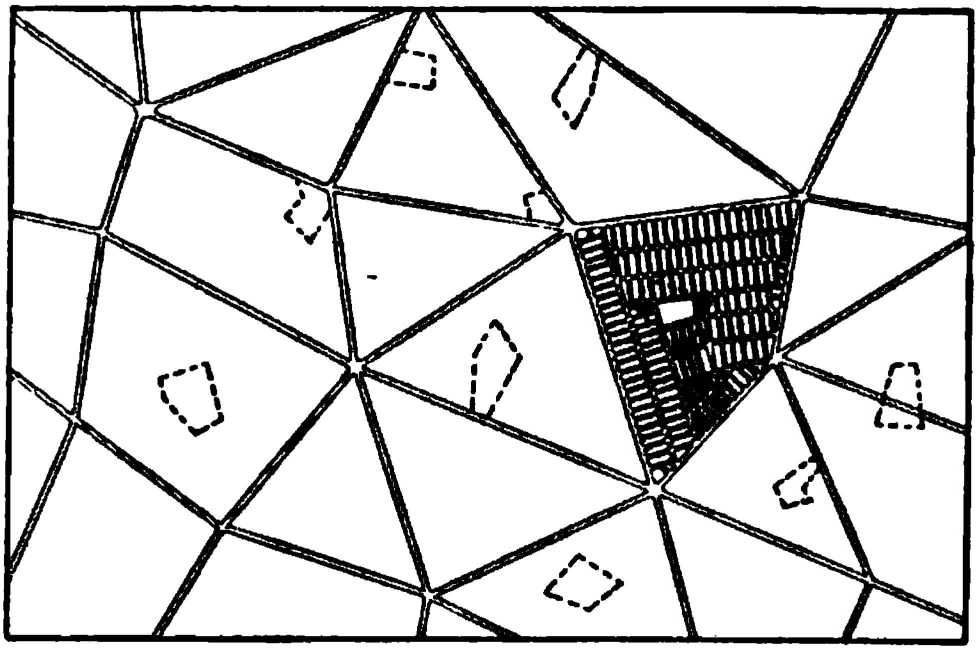

Fig. 4. Typical Plan Showing the Development of an Arterial Street System Making Use of Existing Roads with Additional Connections and the Acquisition of Acreage Property for Small Parks, Building Sites, etc.

The Subject of Street Widths and Alignment will be treated in detail in Arts. 14 and 15, but in connection with the arterial street system it should be pointed out that surface transit lines will probably follow these streets and traffic congestion may develop so that adequate width should be provided. At the same time it is generally conceded that excessively wide streets seldom become important business thorofares. Streets 80 ft wide are likely to develop into better business streets than those 100 ft or more in width, while, with the possible exception of great retail shops, business is quite likely to go to streets 60 ft and sometimes even less in width.

4. Secondary Traffic Streets

The System of Arterial Streets outlined in the preceding Article is designed to meet the general traffic requirements of the city. The irregular areas into which they divide the territory will vary in size as well as in shape; their sides may in some cases be a few hundred feet, and in others a mile or even more in length. In each of them there will be need of secondary streets for business and traffic. Some of these may in time become main traffic streets themselves; some may be used for the relief of the arterial streets when they become congested; some may be occupied by surface railway tracks, but, if the railway transit system is developed

as a unit, the main distributing lines, whether on, above, or beneath the surface, will follow the arterial streets, provided those streets shall have been intelligently planned, while the surface lines which may be located in the secondary streets will serve as feeders to the trunk lines.

Relation Between Arterial and Secondary Traffic Streets. Each of the divisions formed by the arterial street system will be more or less self-contained, having its own secondary centers of business, while connections with other secondary centers in other districts, with railways and shipping terminals or with the roads leading into the country and to near-by towns, will be provided thru the primary system. These secondary traffic streets should, therefore, be direct but not necessarily straight. Their junction with the main arterial streets should be convenient for traffic but should not be too frequent, and a widening at these junctions sufficient to permit a view of approaching vehicles on other streets is always desirable. Intersections of important streets are usually points of traffic congestion and they should not occur too frequently. The highest property values will be along the main arterial streets; too frequent street crossings or intersections absorb an undue amount of valuable frontage and, while corners are of greater value than interior lots for business purposes, a series of streets 60 ft wide, intersecting the most important thorofares every 200 ft will absorb 25% of the entire frontage and interpose too frequent obstructions to traffic.

Widths. There is much difference of opinion as to the proper width for secondary traffic streets. The Royal Commission of London Traffic suggested the following widths: main avenues, 140 ft; first-class arterial streets, 100 ft; second-class arterial streets, 80 ft; third-class streets, 60 ft; fourth-class streets, 40 to 60 ft. These widths for the arterial streets may be over-generous and are possibly due to the unfortunate experience of London, owing to its very narrow streets which have resulted in extreme congestion of traffic. The chief function of the secondary street is to permit ready access to it from the tributary streets and thence to the main street system, thru which in turn the transit system, the transportation terminals, the shops and business centers, the parks and recreation facilities, and places of entertainment may be reached with a minimum of time and inconvenience.

Grades. In planning this secondary street system, regard should also be had to the topography, but not to the degree necessary in the case of the arterial streets, the traffic along them being less in volume and lighter in character. Grades may be somewhat steeper, while advantage may always be taken of the favorable direction of the grade to reach the main street system without long detours, provided, and this is an important consideration, that heavy grades in opposite directions should have between them a low-grade connection with the main system.

Business and Industrial Building Sites. When the main and secondary street systems are still undetermined, manufacturing and business enterprises requiring the distribution of products or goods thru the streets are quite likely to select sites where property is cheapest, even tho they may suffer a perpetual handicap by reason of narrow streets and excessive grades, while if there is a well devised plan of traffic streets which will afford convenient access to all parts of the city, they will be disposed to take advantage of it in the choice of sites, and the hopeless mixture of manufacturing plants, business buildings, and dwellings so characteristic of many cities will be avoided. Arbitrary attempts to segregate industries,

warehouses, shops and residences, are likely to be strongly resisted. Inducements offered to establish them in certain places by making it economical to do so are more likely to accomplish the desired purpose.

5. Transit in the Streets

Development of Transit Lines. While trunk line railways and occasionally interurban passenger lines will gain access to and pass thru a city on their own rights of way, the transit system upon which the vast majority of the people depend for their daily trips, whether for business or pleasure, will be in the city streets, and reasonable provision should be made for it in planning the street system. It is impossible to anticipate just how the city will grow or what transit lines will be required first. It is fair to assume that the transit system will be developed as a unit and not thru the construction of competing lines occupying adjoining streets when needed facilities can be furnished by fewer lines more intensively used and under one management.

Subways and Elevated Railways. In great cities elevated and underground railways may be required on certain streets; these, however, will be few and will be confined to the most heavily travelled routes on which the surface lines will have preceded them. A street which will accommodate a double-track surface railway and leave room for vehicles between the cars and the curb will also accommodate a two-track underground railway with station platforms. Such roads are sometimes built with three or four tracks, but only in very large cities and where there is extraordinarily heavy traffic along a few lines. Elevated lines offer such serious obstruction to light and air and are so noisy and, as commonly constructed, disfigure the streets to such an extent that they will not often be tolerated. In the case of the elevated railroad of Philadelphia, which is built with a solid floor and is stone ballasted, the noise has been greatly reduced. If built of masonry or if the steel structure is incased in concrete, the disfigurement of the street is much less and the noise can be still further reduced. Of the latter class is the elevated railroad thru the Fenways in Boston. The three-track elevated railway in Queens Boulevard, New York City, is composed of a series of arches between piers which are themselves pierced by arched openings designed to accommodate a double-track surface railroad. This street is 200 ft in width, the part in which the elevated railway is located having two roadways, each 43 ft wide. The space between them is 74 ft wide so that there is room for planting on each side of the elevated structure which is itself 77 ft from the side lines of the street, so that there is no obstruction to light and air. With a solid floor, stone ballast, and parapet walls outside the tracks there will be little noise. See Fig. 5. This is probably the best type of elevated railway yet built within street lines. While streets can rarely have such unusual dimensions, if a few avenues leading directly out from the main centers of large cities were given a width of 150 ft, it would

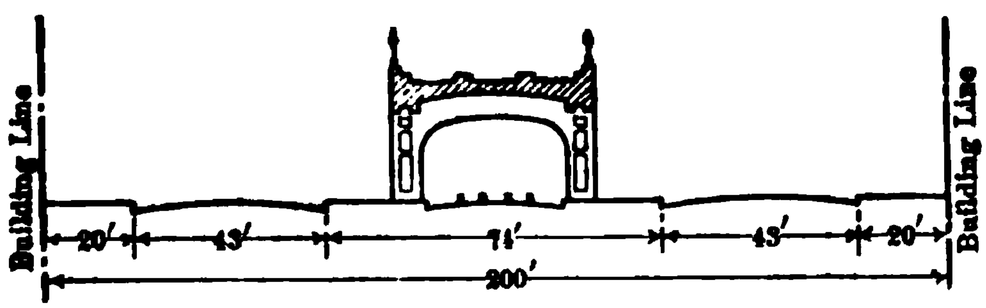

Fig. 5. Cross-Section of Queens Boulevard, New York City

be possible to provide elevated lines of this kind which would be far more agreeable to ride on and would cost much less to build than underground roads.

Cost of Construction of Transit Lines. The difficulty and cost of constructing rapid transit lines in city streets are so great and both are so intensified in narrow streets that the provision of adequate street width for transit purposes is fully justified. In a paper presented to the National Conference on City Planning at Toronto in 1914, J. V. Davies estimates as follows the cost of constructing double-track roads of different types and under varying conditions, the estimates including track and structural equipment but not including power, rights-of-way, easements or franchise charges, while the figures are reduced to cost per mile of single track:

Type of Structure	Cost per Mile of Single Track
Overhead trolley railroad on public roads or private rights-of-way, where no pavement is required	$25 000
Overhead trolley railroad in city streets including asphalt or granite pavement between tracks and 2 ft outside	41 500
Underground trolley railroad in congested city streets, including pavements, conduits and care of subsurface structures under conditions such as those in Washington, D. C.	48 500
Same construction as above under conditions existing in New York City	126 500
Elevated railroad, steel structure, such as built by the Public Service Commission in New York City, including stations	113 000
Railroad in open cut, excavation by steam shovel, concrete walls, including bridges and stations	225 000
Railroad on masonry viaduct, stone ballasted, as on Queens Boulevard, New York City, including stations	330 000
Underground railroad near surface, excavation by steam shovel, little or no interference with subsurface structures, including stations	402 000
Underground railroad in streets like Broadway, New York, extreme interference with subsurface structures, support of surface tracks with underground trolley construction, including stations	1 190 000
Iron tube tunnels, concrete lined, under waterways or below water level, no stations	2 700 000

Construction of Railways in Open Cuts. Where underground railroads will be required ultimately, but where they are built in advance of extensive development and before surface traffic is great, and where streets are sufficiently wide, they can be built in open cuts which need not be covered until the space above them is required for street purposes. In cases where the street width is sufficient, the sides can be sloped and retaining walls omitted until the tracks are covered or the space occupied by the slopes can be used for additional tracks as indicated by Figs. 6 and 7.

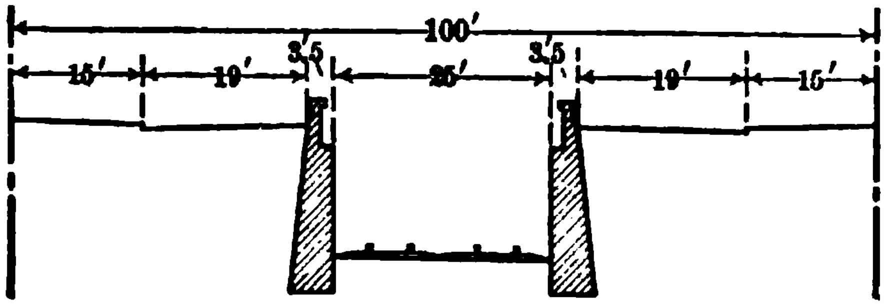

Fig. 6. Showing Open Cut for Rapid Transit Railroad with Retaining Walls in Street 100 ft Wide, Constructed with a View to Converting it into a Tunnel when Necessary.

Surface Railways. By far the greatest mileage of railway lines in any city will be the surface tracks in the streets operated by the overhead trolley system. The inflexibility of the surface railway in comparison with motor-buses or other free-wheel vehicles necessitates a greater roadway width for their accommodation. Unless there is room for other vehicles to pass between the cars and the curb, congestion will result. A New York City ordinance prohibits the construction of a double-track surface railway in any street having a roadway less than 40 ft between curb lines or a single-track railway where the distance between curbs is less than 30 ft. Sidewalk widths on business streets should not be curtailed in order to provide space for surface railroads. Double-track roads are preferable to single-track lines with movement in a single direction and the secondary traffic streets which will or may be called upon to accommodate trolley railroads should be given a width of not less than 70 ft. See Arts. 17 and 18.

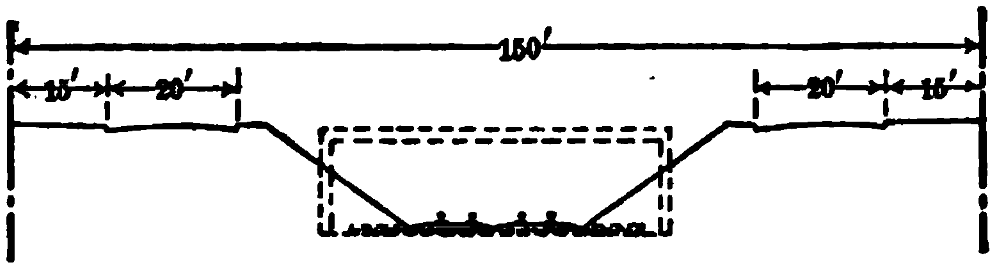

Fig. 7. Showing a Double Track Rapid Transit Railroad with Side Slopes in a Street 150 ft Wide, with a View to Converting it into a Four Track Underground Road when Necessary

6. Access to Terminals

Railway and Shipping Terminals are frequently treated as tho they were, as the name commonly applied to them might be deemed to indicate, the ultimate destination of the passengers and freight arriving at them, or the origin of those departing from them. This, however, is not the case; they are simply the points at which the method of transportation changes. Passengers arriving or departing by thru trains cannot leave or enter them at their own doors. Freight, except in carload lots received by or shipped from manufacturing plants served by spur tracks, cannot be delivered to its destination or shipped directly from its place of production. Both must approach or leave the so-called terminals thru the city streets by means of street railways, private vehicles or trucks. The traffic streets described in the preceding Article must, therefore, afford convenient access to passenger and freight stations and wharves. Confusion and delays are caused when narrow and crooked streets furnish the only approaches to these terminals.

Foreign and American Practice. At the Liverpool Street station of the Great Eastern Railway in London, about 100 000 passengers arrive and the same number depart daily, of which about 71 000 arrive between 6 and 10 A.M. and an equal number leave between 5 and 9 P.M. In addition, there are those using the Metropolitan Underground whose station adjoins and the Central London whose station is underneath that of the Great Eastern, and yet all of these passengers approach and leave thru a maze of tortuous streets varying from a maximum of less than 70 ft in width, including sidewalks, to mere passageways less than 20 ft wide. In marked contrast with this is the central station at Frankfort-on-the-Main fronting on a spacious plaza from which broad streets lead to all parts of the city, see Fig. 8. The Grand Central Station of New York is located on

the axis of a north and south street 140 ft wide with a street 100 ft wide passing in front of it, see Fig. 9.

Street Transportation Costs. Streets leading to steamship terminals are usually congested and the time lost in waiting for the discharge and receipt of freight is a large item in the cost of handling it. Constant movement and the avoidance of delays mean reduced cost of handling goods and less cost to the ultimate consumer. The expense of moving freight a few city blocks from terminal to warehouse or store is frequently much greater than is the cost of carrying it 100 miles or more by rail or water, and this is commonly due to inadequate and inconvenient street approaches.

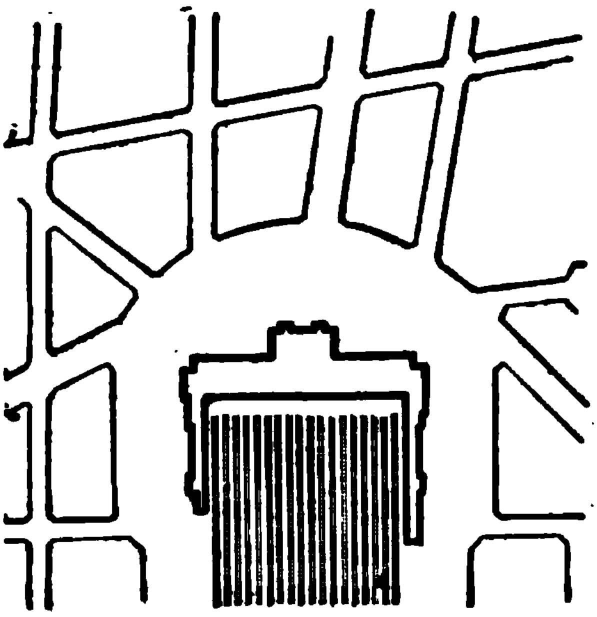

Fig. 8. Plan Showing Location of the Principal Railway Station at Frankfort-on-the-Main, Germany

7. The Environs of the City

Development of Environs. A plan for the future development of a city or new portion of a city will have fallen short of completion if it does not take into account the environs of the city. Local autonomy is so jealously guarded that it is seldom possible to do this officially or as effectively as if a metropolitan planning district were created and some board or commission were given power to make and impose upon the smaller municipal authorities within its limits a plan which would treat the entire district as a unit. This policy is not infrequently followed in the development of comprehensive plans for systems of water supply, sewerage or parks, but rarely, if ever, in the case of a system of highways. Even in contiguous territory, the annexation of which to the city may confidently be expected in the near future, the local authorities and even private real estate developers are allowed, until the very day of absorption into the larger city or town, to proceed with the laying out of streets in an entirely independent manner as tho they were to continue as separate and independent towns having no relation to each other except that of propinquity. Even the cities of Germany, which have powers to regulate their growth and development that are unknown in America, can exercise control over the planning of the territory outside their limits only thru the actual ownership of large tracts of land or in some cases thru an appeal to the authority of the State.

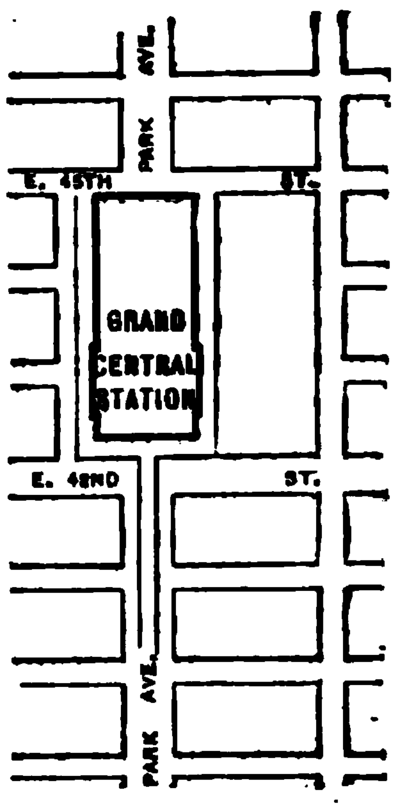

Fig. 9. Plan Showing Location of Grand Central Station, New York City

The British Town Planning Act of 1909 is largely based upon the idea that in a thickly populated country the plan of every town should be considered in its relation to the country about it and to the street systems of contiguous and neighboring towns, all plans being subject to the approval of a central authority whose jurisdiction extends over the whole of Great

Britain. The highway system of every town, whether large or small, should be articulated with the highways not only of neighboring towns but with those of the next larger political unit, the county, and these in turn with those of adjoining counties, the main roads of which should form a complete system of state highways, while the most important state roads should connect with those of other states to form a great national system.

The Chief Highway Joining Two Towns should form a direct connection between the most important traffic thorofares of each. Frequently this is not the case, but the main and sometimes the only adequate road connecting them leads at either end into narrow, tortuous and shabby streets which must be traversed in order to reach the business or administrative center. The impression gained of either will be unfortunate while the pleasure, comfort and convenience of going from one to the other will be greatly increased if the approach, in either case, is thru a dignified, well-improved street constantly increasing in importance and interest until the climax is reached at a well-designed and convenient focal point whether a civic center, the business district, railway terminal or waterfront.

Widths of Trunk Highways. Streets are frequently given a generous width up to the corporate limits of a city where they connect with important and heavily travelled roads, but their width is abruptly reduced at the boundary, notwithstanding the fact that the city is almost certain to extend its limits, when these roads will become city streets and their widening will be necessary. Roads of this kind should be gradually increased in width as they approach a city and the cost of doing so will be slight if it be done in time and in the manner described in Art. 3. The purpose of a road leading from the city into the surrounding country is not solely that of reaching some objective point in the shortest possible time and by the most direct route. Many of the French roads were laid out "from steeple to steeple" or from one town to another in perfectly straight lines, over ridges and across valleys with little regard for easy grades. Such roads are becoming more and more used for pleasure traffic. With the greater speed of motor vehicles, a slightly greater distance is of little or no importance, particularly when by lengthening the roads somewhat the grades will be improved and they can be made in every way more attractive.

Outlying Parks. Cities commonly confine their park areas within their corporate limits but in selecting such reservations the environs of the city should be considered. Some of the most valuable and useful pleasure grounds could be profitably acquired long before the city limits are expanded to include them, and even tho they remain permanently outside of the corporation, if they are made accessible by transit lines, the people will use them. This subject is more fully treated in Art. 11.

SUBDIVISION OF AREAS

8. Principal Residential Streets

Two Classes of Residential Streets. The areas included between the main arterial and the secondary traffic streets will be devoted chiefly to residential purposes, and the principal function of the streets within them will be to provide light, air and access to the dwellings fronting on them. Business traffic will be slight and will be chiefly confined to the supply of the needs of domestic establishments. Such streets will consist of two general classes which may be called the principal and the minor residential streets. On the broader streets will be found apartment houses and the

large private dwellings, whether detached and occupying spacious grounds or in solid blocks with pretentious façades. Apartments and single houses of this class will naturally select the wider streets and, while the engineer cannot determine the kind of development which will take place on each street, he can anticipate the wants of different classes of people, and their tastes and their resources will control their final selection.

The Residential Streets of the First Class will attract a certain amount of pleasure traffic. The abutting owners will be able to pay for a greater area of pavement, wider sidewalks, grass-plots, shrubbery and trees, together with the higher cost of the building lots, owing to the larger proportion of street area to lot area. Such streets should, therefore, be given a generous width. Sixty feet is not enough for successful planting and maintenance of trees unless there is a set-back restriction; 80 ft and in some cases 100 ft will be required. Such streets may be laid out with gentle curves or may have slight deflections, but if their character is to be maintained they should not have abrupt changes in direction and should be long enough to acquire and sustain a distinctive character. They should not connect so easily or directly with the arterial and business streets as to invite the traffic which the latter are especially designed to accommodate. Their chief purpose is to serve houses of the better class, the occupants of which are not entirely dependent upon the city's transit system. While they may contain the show places of the city, those who wish to use them will drive or walk during their leisure hours, and when they are not hurrying to catch a trolley car or a train.

Boulevards or Parkways leading to the parks or connecting the different park units with each other frequently become favorite residential streets, but these are in a class by themselves and are not considered in this Article. The streets bordering parks, however, are likely to become residential streets of the first class, the property values being too high to be within reach of any but the well-to-do or the wealthy. The east side of Central Park in New York City is devoted almost wholly to costly private residences and the other three sides to large apartment houses, while the sides of the streets adjoining the park are much frequented promenades.

Alignment. Long and perfectly straight residential streets become monotonous and uninteresting, while it is quite improbable that they can maintain a fixed character for their entire length. There is no possible reason for extending them in straight lines across business and main traffic streets. It is better to introduce deflections or even offsets at such thorofares and to change their names. This last may be considered a trivial detail but it is by no means unimportant. Every street in a city should have an individuality of its own. If one part of the same street is conspicuous for its fine detached homes, another for its apartments, and still another is devoted to shops, each part is likely to be unfavorably affected by being confused with one or both of the others. In German cities there is a tendency towards a studied irregularity with the express purpose of providing closed vistas and interesting street pictures. This is especially conspicuous in the city of Essen where a deliberate effort is made to limit the range of vision in streets to from 650 to 1000 ft (see Fig. 10).

9. Minor Residential Streets

Requirements for Minor Streets. By far the greatest number of inhabitants of cities and towns live in what may be called minor residential streets. Their homes may be attractive but unpretentious houses, de-

tached or in blocks; they may be in two- or three-family houses, or they may be in the less expensive apartment houses. While some of the latter are likely to be over shops on some of the business and traffic thorofares, most of them will be on the side streets. The traffic on such streets will be slight and the roadway capacity need not be great, but the street width should be sufficient to provide ample light and air and wholesome surroundings. If there is no reason for making the principal residential streets long and straight, there is still less in the case of the minor streets. The

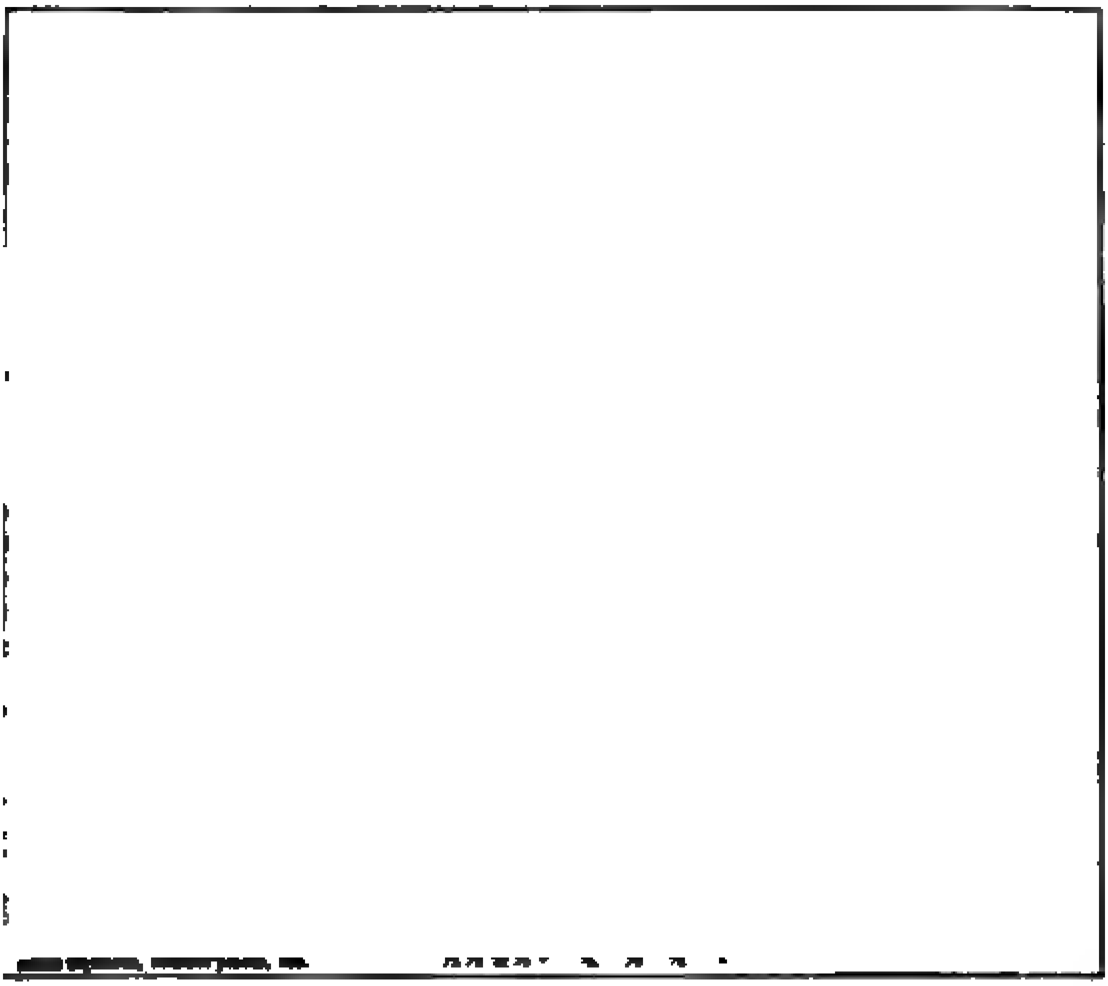

Fig. 10. Street Plan of Essen, Germany

home owners and tenants in them will appreciate the individuality of their streets fully as much as will those living in the more important avenues and boulevards.

The Cost of the Lots is of great importance and will depend in great measure upon the amount of land which is devoted to public use. The streets should be no wider than is needed for good sanitation, and the longer the blocks, the less area must be taken out for cross streets. Sixty feet may be considered a maximum width for such streets, but the minimum will depend upon whether there are restrictions as to building heights and the proportion of the lots which may be built upon. The absence of such restrictions compels the creation of wider streets to guard against the blighting effects of high tenements covering nearly all of the lot area,

and thereby imposes upon both home owner and tenant who want to live decently an unnecessary and unfair burden in the cost of the street and its improvement. With such restrictions the street widths could safely be reduced to 40 and even to 30 ft for very short streets, in the latter case only half as much land being required as in the case of 60-ft streets which are designed to provide for the possible erection of high buildings.

It occasionally happens that irregularly shaped blocks will be left which are too large for economic subdivision into building lots, while they are too small to be divided into two or more separate blocks without imposing too great an expense for streets. The interior portions of such blocks have frequently been made available for profitable use by the creation of one or more narrow CUL-DE-SACS. While such streets are often picturesque, particularly when provided with an enlargement for a turning space at the inner end, they are always objectionable on sanitary grounds, and involve serious fire risks. In general no street should have but a single outlet. In such cases very satisfactory results can be secured by the creation of a small open space or court in the interior of the block provided it is given not less than two outlets. Such an arrangement is shown in Fig. 11, where an open space in the interior of an irregular block is provided with three outlets by means of streets 20 ft wide. This affords frontage for more lots than would be the case if the block were undivided and will more than compensate for the loss of three 20-ft lots on the bounding streets which are appropriated for the outlet streets.

Fig. 11

The Most Depressing and Irrational treatment of streets of the kind under consideration is the adoption of a stock plan with uniform block dimensions covering an entire section and even, as is frequently done, extending over several of the adjoining sections into which the business and traffic streets divide the city. Washington offers an illustration of a rectangular plan upon which has been superimposed a great system of broad diagonals connecting every part of the city. This may be a suitable plan for a great national capital, where the greater part of the cost is paid out of the Federal treasury, but is too extravagant for the ordinary city. The open spaces formed by the intersections of the avenues are treated as parks and are very beautiful, but even Washington has its slums. The more intimate short street in which the speculative builder cannot erect uniform rows

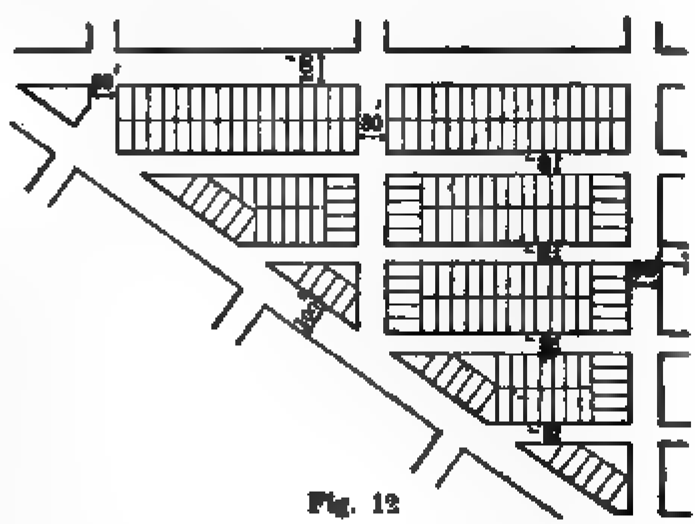

Fig. 12

of exactly similar box-like dwellings makes it possible to give character and even a certain distinction to the most modest street.

Alternate Plans for a Triangular Area. Figs. 12 and 13 show alternative treatments of a triangular area, bounded by two streets 100 ft wide and a third 80 ft wide. Fig. 12 shows the conventional treatment so commonly followed and which is the actual arrangement in this case, which is a part of the plan of an American city, with 60 ft streets in one direction, crossed by 80 ft streets at right angles, and having roadways 30 and 44 ft wide respectively. In Fig. 13 the streets are 40 and 50 ft wide, with roadways of 16 and 20 ft, while a little more than half an acre is devoted to a small neighborhood park. The area between the three wide streets is 24.93 acres, and the land is assumed to cost $3000 an acre. The building plots in one case are 40 ft wide and 100 ft deep, and in the other 50 ft wide and 60 ft deep. The estimated cost of development and the cost of each plot are as follows:

Fig. 13

	Original Plan Fig. 12	Alternative Plan Fig. 13
Cost of land	$74 790	$74 790
Curbing	2 919	4 625
Sheet-asphalt pavement	31 054	26 658
Cement-concrete walks	8 848	10 480
Sewers	4 954	9 360
Total	$122 060	$125 908
Or if a water-bound broken stone roadway is substituted for asphalt	$108 985	$113 528
Total number of plots	204	259
Average area of plots	4 041 sq ft	3 023 sq ft
Cost per plot with sheet-asphalt pavement	$598.33	$486.10
Cost per plot with broken stone roadway	533.75	438.33

The saving to the purchaser of $112 a plot in case the streets are paved with sheet-asphalt and of $95 a plot in case they are paved with macadam will mean a great deal to him. The small park will also mean much to his family and the entire character of the neighborhood will be improved by reason of the fact that it will acquire a certain individuality which would be impossible if the improvement had been carried out in a conventional manner.

10. Block and Lot Dimensions

General Discussion. It would naturally be supposed that the position with respect to each other of the arterial and secondary streets would determine the block dimensions and that these in turn would control to a

large degree the shape and dimensions of the building plots. But there has been a disposition, especially in American cities, to reverse this sequence, to adopt a standard size and shape of lot which has been persistently adhered to and this has resulted in a standardized size and shape of block. These blocks, laid out in series and separated by streets of uniform width, have been a controlling consideration in the location of important streets. While the lot units vary in different cities they are usually the same in any one city. In New York and many other cities the lots are 25 ft wide by 100 ft in depth, the same size and shape being used in the best and poorest residential districts, in the parts of the city devoted to business and manufacturing and even in the warehouse districts along the waterfront. These lots are combined in blocks which are 200 ft wide and from 600 to 800 ft long. There may have been a logical reason for the adoption of such a unit when the city was first laid out, but it has become a habit which has persisted under changed and constantly changing conditions. If a manufacturing enterprise requires a large plant which cannot be accommodated in a block 200 ft wide it is usually necessary to place it in a locality where the streets have not yet been opened to public use, as, once they have been so opened, it is difficult to close them, and there are instances where such plants have been obliged to move entirely outside of the city in which they were located in order to secure room for necessary expansion and increase in facilities.

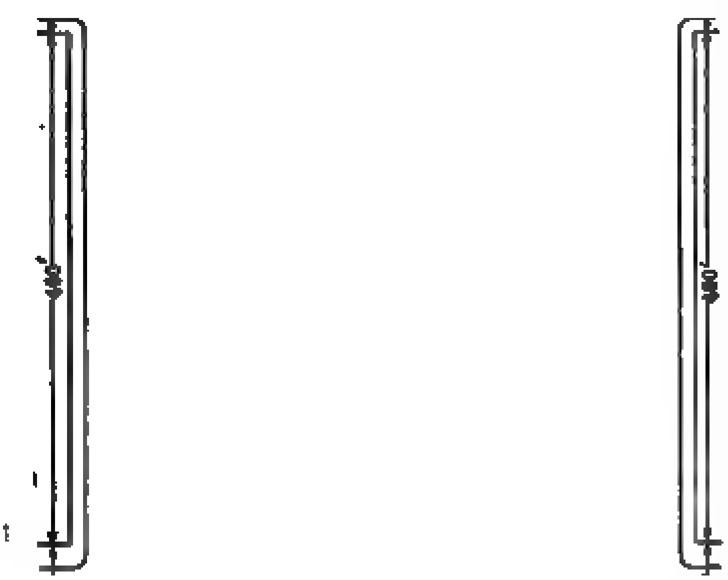

Fig. 14. Typical Method Employed in Philadelphia in Subdividing Blocks 396 ft by 400 ft in Size

In Residential Districts also, whether devoted to costly detached residences, to compactly built tenements or to small one or two-family houses, the same inflexible rule is followed. The same number of square feet must be acquired for each foot of frontage, regardless of whether it is more or less than is required for the use to which the land is to be put. That this lot unit is not an economic one, at least as to width, is indicated by the fact that, altho it still persists as a sales unit, it is quite generally disregarded in building operations, especially in sections where buildings are erected in solid blocks. Houses with frontages of 25 ft are rarely found in large cities. Expensive houses are sometimes wider, but it is said that the prevailing house frontage in New York City is now about 17 ft, while it is often 13 ft 4 in, and sometimes only 12 ft 6 in. Chicago has a lot unit of 25 ft in width and 125 ft in depth which appears to be almost as persistently adhered to as is the 25 by 100 ft lot in New York. In Phila-

delphia a considerable portion of the city was originally laid out in blocks 396 by 400 ft bounded by streets 50 and 60 ft wide, and in order to provide for the small single family houses so characteristic of that city, these blocks have frequently been divided into smaller blocks by introducing two additional streets 40 ft wide resulting in the creation of 168 building plots, varying from 14 to 16 ft in width and from 49 to 60 ft in depth, with a passageway 3 ft wide separating the lots in the rear. The city ordinances prescribe a minimum width of 14 ft for any dwelling house and a minimum open space of 144 sq ft for each lot and these lots are used to the greatest allowable extent, while some builders have attempted to count the rear passageway in the required open space. A typical plan of such subdivision is shown by Fig. 14. This may be better than four and five-story tenements on lots 25 by 100 ft housing four families on each floor, but it is a too intensive use of the land which Philadelphia is trying to find some means of correcting. A very satisfactory and attractive manner of subdividing a block 200 by 700 ft for high-class, semi-detached houses has been adopted

Fig. 15. Arrangement of Semi-Detached Houses with Central Heating Plant, A, Supplying Heat and Hot Water to Houses on Both Sides of the Street

to a limited extent in the Borough of Brooklyn, New York City, and is shown by Fig. 15. In this block there is a central heating plant built below the surface of the back yards, the chimney of which is combined with that of a church at one end of the block.

Manufacturing and Warehouse Districts. In portions of a city which, by reason of transportation facilities, are particularly adapted to manufacturing or warehousing it is better to leave considerable areas unsubdivided, and there is no reason why such streets as are laid out should be placed at such distance apart as will insure future division into blocks of any particular size. The streets which are located should permit the widest latitude for the development of such enterprises as may seek accommodation. It is especially desirable that waterfront property should not be unduly restricted by placing the first street parallel with the water so near it that there will not be room for the economical receipt, shipment and handling of raw material and manufactured products. These streets are often placed immediately next the water, thus seriously interfering with such enterprises. At least 200 ft is likely to be needed for such purpose, while 300 ft or even more is frequently required. Waterfront property is usually expensive and those who develop plants requiring such facilities will not

buy more than is needed, but they should be able to secure enough and to feel secure in its uninterrupted use. There are portions of the waterfront which will be developed with quay walls for open wharfage or with piers for the accommodation of regular steamship lines and in these cases a public marginal street will be needed. There is a tendency for cities to acquire and develop their entire waterfront as a municipal enterprise, either for substantial net revenue or for operation at cost in order to stimulate commerce. Even under such a policy a considerable part of it could properly be leased for manufacturing or warehousing in which case space could well be allowed for the same development as would naturally take place under private ownership and control.

11. Reservation of Park Areas

Factors Influencing Selection. The park reservations of a city should be considered in connection with the street plan. A common practice is to lay out the entire area into streets and leave for future consideration the selection of the park spaces, a single block here and there and in some cases a number of blocks being taken for the purpose, the streets within the area being wiped out. If such a policy be followed, the park system will necessarily be adapted to the street system, whereas the park system should to a certain degree control the street system. The location of parks should be determined by topographic features, and such reservations can best be located before or at the same time as the main street system. This does not mean that the engineer who is responsible for the preparation of the street plan must also determine the precise area and location of the city's future parks, but that he must keep in mind the need of parks, and should not carry the street system across areas peculiarly adapted to this purpose. Such areas should be left without subdivision, and at the same time provision should be made for streets of adequate width leading to them and connecting them with each other, in order that when the system is finally developed these streets may serve as parkways. The future park needs of a city cannot be predicted. Charles D. Lay, formerly Landscape Architect of the New York Department of Parks, has estimated the park needs of a city of 100 000 population as 1500 acres or on a basis of 12.5% of the city area, these parks ranging in size from large wild parks to small gardens and squares. His estimate is based upon a density of population of but 8⅓ persons per acre and an allowance of one acre of park to 66⅔ persons, but the only cities that approach these figures are Washington and Boston. To show the wide variation in park reservations with respect to area and population and the futility of attempting to estimate such needs in advance, park statistics of a few cities are given in the table on the following page.

Connecting Parkways. If there are tracts of land so obviously adapted to park purposes that they will probably be acquired for that purpose, streets leading to them and connecting them should be laid out of such width that they can be converted into parkways and can be developed with some park features, such as planting and several roadways. Such streets will become a part of the park system and with that use in view their development into business thorofares should be discouraged. Experience seems to show that streets more than 100 ft wide rarely attract business, so that if those which will serve as park approaches or connections

are given a width of 120 to 150 ft business will be likely to avoid them, while such width will permit the kind of treatment which is desirable when the time comes for their improvement as a part of the park and boulevard system.

Neighborhood Parks. Important as are the large parks and the parkways of a city, those which mean most to the greatest number are the smaller neighborhood parks, one of which should be within easy walking distance of every part of the city. These can usually be provided within the space of one or two city blocks and, as they are generally treated in a formal manner, topographical features are not an important consideration. It is difficult to locate them long in advance, nor is it desirable that this be done provided they are selected and acquired before they are built upon

	Population per Acre	Percent of Area Devoted to Parks	Population per Acre of Park
London (county)	60	9	677
New York	28	4	689
Chicago	19	4	545
Berlin	183	7	2 014
Philadelphia	20	6	322
Munich	27	8	356
Cologne	19	3	781
Düsseldorf	15	10	149
Washington	9	14	68
Kansas City	8	5	144

or the land becomes valuable by reason of rapid development of the property in their immediate vicinity.

Acquirement in Advance of Development. Whether the parks be large or small it will be advantageous to acquire them at as early a date as possible and before the tracts selected are subdivided into lots. If bought as acreage property, the entire holdings of one or more individuals or estates being taken, there will be no consequential damages to pay by reason of the leaving of unsalable remnants. Irregularity in the boundaries of the tract will not be objectionable, particularly if the area be more than will ultimately be required. When the street system shall have been developed and the final park boundaries shall have been straightened out there may be a few lots or several blocks left. In the latter case admirable sites for schools or libraries will be provided, more advantageously located and at far less cost than if they were purchased separately. In either case the surplus property may be sold, if this is permitted by law, at the increased price created by the establishment of the park and the location of buildings of this character, and the receipts may go a long way towards paying the cost of the park itself. See Fig. 4.

12. The Location of Public Buildings

Public Buildings Defined. The designation, public buildings, is commonly used in a very restricted sense and as applying only to those in which the business of the nation, state or city may be conducted. In their relation to city planning there are many others which can prope-

be called public buildings, not only such as libraries and museums which are much frequented by the public, but all of the buildings constructed and maintained for the exercise of any of the functions performed by public authorities, such as schools, penal and charitable institutions, markets, hospitals, police and fire houses, baths, and structures connected with water supply and drainage. They may also include churches and buildings used for amusement and entertainment under private as well as public management, and the various buildings and plants, many of which in European countries are maintained by the municipalities, but which in America are commonly left to public service or other corporations, among these last being railway stations and terminals, lighting and heating plants, financial institutions, and even places of public amusement.

Grouping. Much attention has lately been given to the more convenient grouping and arrangement of such buildings but the usual aim has been to secure better architectural effects. In order to accomplish this, open spaces have been created, streets have been widened, and new streets have been laid out and opened thru blocks which have been completely built up. While the precise location of such buildings cannot be determined far in advance, the administrative center of a city will have been so definitely fixed early in the city's development that it will rarely be changed. The provision of sufficient space to give such buildings a dignified setting is of the greatest importance. The location of streets which will provide suitable approaches to them is equally important. These will not only promote the convenience and save the time of those having occasion to visit such buildings but will add greatly to the general appearance of the town. Every large city will have other centers than what may be called the administrative center. There will be an educational center where the more important educational buildings, the libraries and the museums should be located. Such buildings will require ample space and approaches from which they can be seen to advantage. The importance of ample space about and convenient access to transportation terminals has been emphasized in Art. 6. Other public and semi-public buildings will be required, the most advantageous location of which it is impossible to determine. The important consideration in designing a street system is to provide suitable and dignified locations which can be availed of for such purposes and not create a situation where they must be given inconspicuous sites or new streets must be cut thru in order that they may be reached conveniently and seen to advantage. See Fig. 4.

Secondary Public Buildings. There are still other types of public buildings which are far more numerous than those last mentioned and which are commonly located in a haphazard fashion, wherever the most available or the cheapest property can be acquired for them at the time they are needed. The buildings referred to are of two classes to which different kinds of location are best suited. In one class are schools of various grades, branch libraries and public baths which need not be and should not be on the main traffic streets. Their location will depend to a large degree upon the distribution of population; but if certain blocks in different parts of the city were set aside for them, they could be grouped together and be designed in harmony with each other with sufficient space about them to insure abundant light and air and with room for future additions, the space for which, until needed, might well be devoted to playgrounds. Such block would be peculiarly well suited to the purpose if the street system be sufficiently irregular not to invite traffic. The other class would bus

include such buildings as police stations, fire-engine houses, repair shops, a municipal garage or stable, and buildings of this character. These could also be designed to harmonize with each other and form a consistent group. They would naturally be located on or in close proximity to the more important thorofares in order that the territory which they serve may be easily reached. In either case, such municipal blocks would be creditable to the city, while the problems of heating, maintaining and caring for them would be greatly simplified.

13. Control of Private Developments

Development by Real Estate Operators. One of the most difficult problems confronting the engineer engaged in the working out of a suitable street plan is the control of the development of property by real estate operators in advance of the preparation of a final plan or without regard to such plan if one shall have been prepared and the streets have not yet been laid out on the ground and taken over for street purposes. Such developers buy acreage property and their chief purpose is to convert it into as many building plots as possible and dispose of them as quickly as they can. They are rarely interested in the future character of the neighborhood or in the welfare of the purchasers. They have little interest in the relation of such a plan as they may adopt to that of neighboring developments or to plans which are under consideration by the public authorities charged with the responsibility of preparing them. In most cases the right of an owner of real property to make such use of that property as he pleases until it is taken from him by due process of law is guaranteed to him by statute or constitution. The city may have declared its intention to adopt a certain street plan. It may even have formally adopted one and may have taken the initial steps to acquire title to the streets, but until such title has actually been secured the courts will generally protect the owner in selling lots which are located without regard to street lines and even in erecting buildings within the proposed streets, and will grant them full compensation for damages which may be imposed by the taking of the property, just as tho these lots had been sold and buildings erected in good faith years before an official plan was thought of. The purchasers of such lots are usually innocent, tho foolish, and upon them will fall the hardship and inconvenience of adapting their property to such changes in the layout according to which they have bought as will make it conform with a reasonable plan consistent with that of the adjoining sections. The original developer will have unloaded and escaped with his profit before this time comes.

Relation Between Private and Public Street Systems. But it is not always the man or the corporation who laid out his property as he wished without regard to any comprehensive plan who is wholly to blame for the burdens placed upon the subsequent owners. Such layouts are sometimes impossible and must be substantially changed or altogether ignored, but sometimes they are disregarded because they do not conform with the preconceived notions of the engineer who, whether actuated by a passion for regularity and geometrical symmetry or entirely indifferent to the hardship imposed upon innocent purchasers, will project a rectangular street system across anything which interferes with it. The new system may exist only on paper for years and, meanwhile, building will continue in accordance with the original layout until the expense of changing it be-

comes so expensive that the new plan has to be entirely abandoned and the old streets are adjusted to those of the official plan as well as may be, with results far less satisfactory than would have been the case had a serious effort been made to reconcile them as far as possible when the official plan was made. Numerous instances of this policy might be given, but an actual case of the result of carrying a rectangular street system across an old settlement is shown by Fig. 16.

Legislation, Existing and Proposed. Laws have been enacted which have declared that when street lines or the boundaries of parks have been

Fig. 16. Plan Showing the Disregard of Existing Improvements by carrying a Rectangular Street System Across Old Streets which could, without Serious Objection, have been Incorporated in the Plan

fixed by competent authority, any one who subsequently erects buildings within the lines of any such street or park shall not be entitled to receive damages for them when the property is taken for the purpose for which it is designed Such statutes have often been declared unconstitutional, but in Pennsylvania laws of this kind have been found to be so obviously in the public interest and public sentiment is so strongly in favor of them that they have not been contested. It must be admitted, however, that there is some danger of injustice in unreasonably delaying the actual taking

of property for such a public purpose and thereby depriving the owner of the reasonable and profitable use of his land. After a city has, by the adoption of a plan, indicated its intention to take property for a public purpose, it may not be feasible immediately to incur the expense of the acquisition of such property, but if an owner of any parcel, acting in good faith, indicates his desire to improve such a parcel by the erection of a building, the city might fairly be required to promptly take and pay for any such parcel in order that it may not unnecessarily deprive the owner of the profitable use of his property. To prevent the plotting and selling of lots without regard to a final plan or in advance of the adoption of such a plan, it has been proposed to enact laws requiring that any such owner shall not offer for sale lots purporting to front upon public streets until the plan showing such proposed streets shall have been submitted to and approved by the municipal authorities having jurisdiction and control over the preparation of the street plan of the city. Such a provision would be difficult of enforcement, but the desired end could probably be attained indirectly by making it illegal for any office of record to accept and record a street plan or layout prepared by a private developer in accordance with which it is proposed to sell building lots unless such plan should have been first approved by the proper authorities. Real estate operators are always desirous of having such plans recorded and their inability to do so would make it much more difficult for them to market their property. It has also been proposed that offices of record be forbidden by statute to accept and record conveyances of property fronting upon what purport to be city streets unless the plan of such streets shall first have been approved by the municipal authorities. The city and town planning law enacted by the Legislature of New York, Chapter 699, Laws of 1913, which provides for the creation of city and village planning commissions, distinctly authorizes the body creating such commissions to provide that no plan showing the layout of any highway or street upon private property or of building lots in connection with any highway or street shall be received for record in the office of the clerk of the county where such property is situated until a copy of the plan has been filed with such commission and it has certified its approval thereof.

THE INDIVIDUAL STREET

14. Economic Street Widths

The Purpose of the City Street is two-fold: to afford light, air and access to the abutting property, and to provide accommodation for such traffic as may pass thru the street but the origin and destination of which may be elsewhere, the route followed being that of least resistance in the case of business traffic and that which is most agreeable in the case of pleasure traffic. The width required for light, air and access will depend upon the height to which the buildings may be built and the proportion of the lots which may be covered; in other words, upon how intensive a use is made of the land. The greater the amount of space which is given up to streets in proportion to building plots, the more expensive will be the land which remains for development. Very narrow streets mean lack of light and air, unsanitary conditions and traffic congestion; unnecessarily wide streets mean a serious burden upon the abutting land, the price of which must include the value of that taken for streets, greater expense to the lot owner

for street improvement, and additional cost to the city for maintenance and cleaning, while grass-grown roadways lined with shabby buildings out of keeping with the street improvements often tell a story of an ambitious plan which has resulted in pitiful failure.

Economic Relation of Street Widths and Lot Areas. Excluding parks and other open spaces, the percentage of the platted area of a city which is given over to streets varies from 25% to about 50% and is in most cases about 30%. This means that the owners of property are required to pay for an area varying from one-third of the land which they actually own to an amount equal to their holdings, of which they can make no profitable use. This is so serious a burden that the proportion of the total land which is actually required for streets is worthy of the most careful consideration. It is fair to assume that the width of street required is proportional to the depth of the abutting lots as, with reasonable restrictions governing the use of the land, which are commonly expressed in a percentage of the area which may be built upon, the business or the street use which the abutting property will create will vary with its depth. If, then, 50 to 60 ft is the proper width for an ordinary street with lots 100 ft in depth, plots 60 ft deep will not require a greater street width than from 30 to 40 ft. On streets where lots are 125 ft in depth and the streets are 80 ft wide, a decrease of the lot depth to 100 ft or even to 75 ft might justify a similar decrease in the width of the street to 65 or even to 50 ft. This argument would be unsound in the absence of stringent regulations limiting the height to which buildings may be built and the proportion of the lots which may be covered. Even in this case, however, there are certain streets which will probably be occupied by surface railway tracks and these should be given a width sufficient for the purpose without regard to the depth of the lots which front upon them. In general it may be said that while the streets which from their positions and grades are likely to be used by street railways should not be less than 70 ft and preferably 80 ft in width, other streets should be in proportion to the depth of the abutting lots, and that the total street area should be from 25 to 40% of the combined area of streets and lots as may be determined by the probable nature of the development or the ability of the lot owners to pay for more or less space in addition to their lots in order to give the neighborhood in which they are to live a certain distinctive character.

15. Alignment and Grades

Alignment. The uselessness, if not the folly, of laying out streets in perfectly straight lines has been noted in Arts. 4, 8 and 9. In the principal and secondary traffic streets directness is important, but the difference in distance along a rectilinear highway and one whose general direction is uniform but which has occasional slight changes in its course is so slight as to be almost inappreciable and is entirely immaterial. The free movement of traffic is greatly obstructed by right-angled turns and the time consumed in following a series of courses where a rectangular street system makes it necessary to do so in passing from one point to another in the absence of diagonal streets is more than that due to the increased distance. Deflections up to 30° and perhaps more offer no obstacle to free movement, and even at junctions of important traffic thorofares the confusion and delay caused by the intersecting streams of traffic are less if they come together obliquely, as it is quite unlikely that traffic would attempt to pass around

the acute angle, and if it did, police regulations should not permit it. Aside from the saving of time and the avoidance of confusion, abrupt changes of direction involve a certain amount of danger which varies inversely with the distance at which approaching vehicles can be seen.

Traffic and Residential Streets. The main arteries of traffic either extend from the business center or the railway and waterfront terminals to the outlying portions of the city or they may traverse the entire city from one side to another. Such routes may include several different streets, but because they have different names is no reason why they should be considered separately with respect to their alignment and grades. They form a single unit in their relation to street traffic and should be so considered. In the case of residential streets the conditions are entirely different, as are the functions of such streets. With the exception of such principal streets and boulevards as were noted in Arts. 8 and 11, each one of these streets is a separate unit and need not be considered in its relation to others. Its traffic will be slight and directness of movement is not important. The only advantage of the rectilinear street for residential purposes is that it permits the abutting property to be economically divided into rectangular lots, which at the present time seem to be more readily salable, and if the purchaser wants a standardized lot and house precisely like his neighbors, the straight street and rectangular block offer some unquestionable advantages. So far as the general public interest is concerned, not only is there no reason for rectilinear residence streets but a departure from the standard plan so much in vogue will add interest and variety to the city. There is danger, however, that in trying to avoid the commonplace by the introduction of certain irregularities one may go to the other extreme by the adoption of what Unwin has called mere "aimless wiggles." An illustration of the result of such a treatment is to be found in one of the suburban districts of Toronto, where a system of curvilinear streets has resulted in a very attractive development but, while the topography is somewhat irregular and picturesque, it does not justify the excessive amount of curvature which was introduced.

Alignment and Grades Must Be Considered Together. Many streets have been definitely laid out and imposed upon the city plan before their grades have been determined or even seriously studied. It is afterwards found that in order to secure such moderate rates of grade as the importance of the street as a traffic artery would demand, heavy cutting or filling is required which will impose upon the abutting property a burden which is not only unnecessary but which may effectively prevent its development in the manner which the assumed character of the street would naturally demand. Had the grades been considered in connection with its location, that location would have been modified even at the expense of a detour with some added distance. No specific figures can be given as to the practicable limit of grade for streets of different classes. The tables which have been so often given showing the tractive force required to move a certain load on various roadway surfaces having different rates of grade are of doubtful value; not as to their accuracy for the conditions under which they were established, but as to their applicability to conditions which may actually exist. Grades which are prohibitive for horse-drawn vehicles are of little concern to motor vehicles altho they impose a lower speed. Even in the case of electric street railways, grades of 6, 8 and 10% involve no difficulties as to the traction problem but they do involve serious danger from slipping under certain weather conditions. Grades which

are considered prohibitive in some cities are deemed quite moderate in others. San Francisco has many street grades of 20% and more, and in one case a double-track surface railway is operated in a street having a grade of 26.5% (see *Eng. News*, Feb. 18, 1915). The horse will continue to be used in city streets and horse-drawn traffic must be considered. The obstacle offered by a grade is proportional to its length, altho there is an absolute limit to the slope which is practicable for heavily loaded horse-drawn vehicles. If that limit is exceeded, a detour at a lighter grade must be followed and if, in the case of an important street, such detour involves considerable increase of distance, the portion which has the excessive grade or the long detour will not become the traffic artery which its location appeared to indicate. In the case of residential streets neither grades nor alignment are an important consideration. The traffic in such streets is that needed to supply the needs or to minister to the pleasure of those living in them. The coal dealer may prefer to supply a patron on such a street by delivery in a 6-ton truck, but if the grade is too heavy for that, he can deliver in smaller loads and no public interest will suffer. Residential property located on a hill affording a fine view will always be desirable, none the less so because it must be approached by a steep grade for a short distance. In such cases both grade and alignment should fit the topography as closely as possible so that natural features need not be disturbed, let the lines and grades be what they may. Either lines or grades may be improved at the expense of the other, and it will always be a matter of judgment and taste which should give way, and no definite rule for such cases can be formulated.

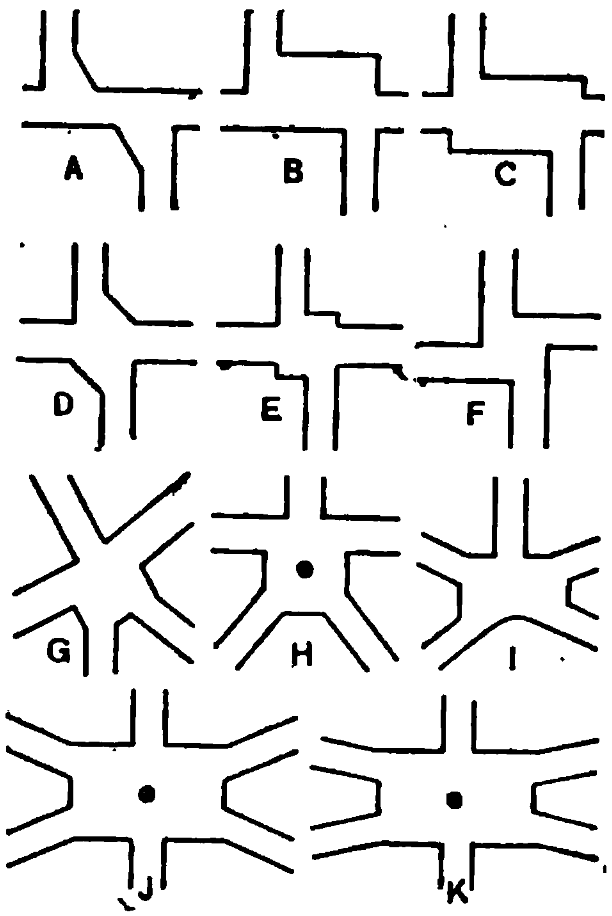

Fig. 17. Some Examples of the Treatment of Street Junctions by a Slight Enlargement of the Open Space

16. Street Intersections

Street Intersections Form Either Junctions or Crossings. In the former case, lines of traffic converge and flow along a common course without serious inconvenience in the case of acute angles and with considerable interference and confusion in the case of rectangular junctions. In the case of crossings, the interference with free traffic movement is greater. The most awkward intersections are those where there is an offset in the crossing street involving two right-angled turns. While an enlargement of the street area is desirable at all intersections where any considerable traffic may be expected, it is especially necessary where there are offsets. Such breaks in the continuity of a street have the advantage of affording opportunities for interesting street pictures and advantageous sites for buildings which require ample light and which are worthy of sites which enable them to be seen to advantage. Several methods of treating offset intersections are shown in Fig. 17, from which it will be seen that by the acquisition of a slight additional area very pleasing results can be secured.

At acute-angled intersections the street lines may be deliberately shifted in order to break the alignment without the slightest embarrassment to traffic, while the streets will acquire added interest and some admirable sites will be provided for important buildings as illustrated by Fig. 17, J and K.

Enlargement of Street Area at Intersections. Where two important streets intersect either at right angles or obliquely, an enlargement of the area is always desirable, the open spaces being either rectangular or circular in form and occasionally irregular in shape. The circle is best adapted to cases where five, six or more streets come together when it can be made a conspicuous feature of the general plan. Among the symmetrical places of this kind are the Place de l'Etoile with its twelve converging avenues and the Arc de Triomphe in its center, and the Place de la Nation, where ten streets center at the bronze group representing the Triomphe de la République, both of these places being on what might be called the main axis of the city of Paris. Other examples are the circular place at Indianapolis with a diameter of 493 ft and the tall shaft of the Soldiers Monument in the center whence the four principal streets of the City radiate, and Columbus Circle in New York, 430 ft in diameter, where six important streets join at the Columbus Monument. Washington has many open spaces at the junctions of its great diagonal avenues with each other and the rectangular streets. These, however, are treated not as traffic centers but as parks, and are planted and adorned with monuments or statues in a manner suited to a great national capital.

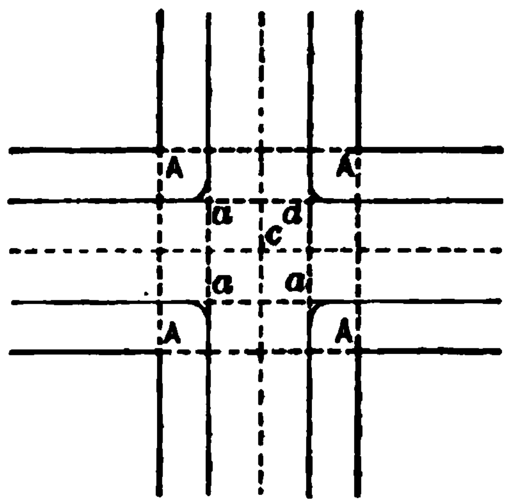

Fig. 18

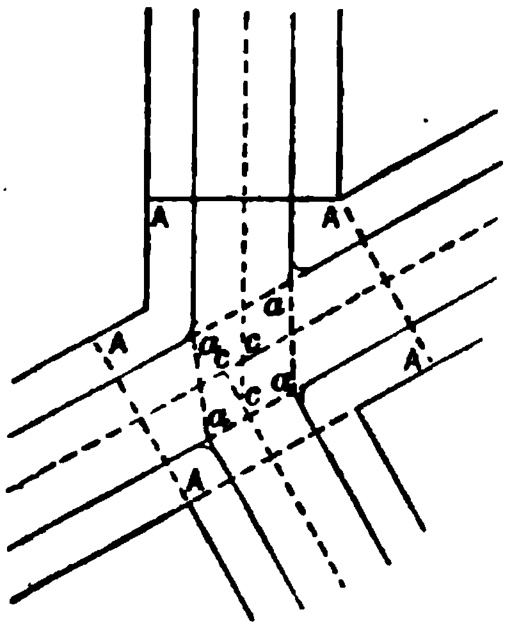

Fig. 19

Platform Grades at Intersections. A detail of street intersections, the importance of which is not generally appreciated, is the establishment of platform grades or the interpretation of grades shown upon street plans. It is a common practice to indicate on such plans the grade elevation of the intersection of center lines. Where grades are very light platform intersections can be worked out with a fair degree of uniformity by different persons, but where the grades are steep and the intersections are irregular no two persons are likely to agree in their interpretation without some definite rule to govern them. This subject has been comprehensively treated by V. S. Moon, Assistant Engineer of the Board of Estimate and Apportionment of New York City (36), who recommends the following rules for the interpretation of grades at street intersections:

"1. **Definition of Platforms.** The CENTER LINE INTERSECTION shall be deemed to be the point of intersection of the center lines, except for cases where the center lines do not meet at a common point, when it shall be the area included within the center lines at their intersection (shown as point c and area ccc, Figs. 18 and 19).

"The CURB LINE PLATFORM shall be deemed to comprise the area included within the lines connecting the points of intersection of the curb tangents, or in the case of

a street terminating at another street it shall comprise the area within the prolongations of the curb lines across the intersection and a line joining the curb tangents (shown as areas aaaa, Figs. 18 and 19).

"The BUILDING LINE PLATFORM for rectangular intersections shall be deemed to include the area bounded by the prolongations of the building lines of both streets across the intersection so as to comprise the greatest platform area. In the case of other than right-angled intersections, it shall comprise the area bounded by the respective lines of each street and by lines at right angles or normal to the center lines and passing thru acute-angled building line corners, or the corners giving the greatest platform area. If the intersection of the center lines falls without the Building Line Platform, as above described, the said platform shall be increased sufficiently to include the said intersection. When the building line corner is turned with a curve the platforms above defined shall be indicated upon the map unless herein definitely fixed. The Building Line Platform is defined by the lines AA, Figs. 18 and 19.

"2. **Definitions of Elevations Fixing Grades.** Unless otherwise indicated on the map, the elevations shown at a street intersection shall be deemed to be that fixed for the point of intersection of the center lines of both streets affected, or for the Center Line Intersection.

"3. **Treatment of Center Line Intersection.** The Center Line Intersection, when it comprises an appreciable area and unless otherwise shown on the map, shall have a uniform elevation at its boundaries, and in determining the elevations for the other platforms herein described the Center Line Intersection referred to as a basis of calculation shall be deemed to be the nearest point on the center line of each street at the boundary of the said platform.

"4. **Treatment of Platform for Streets Having a Light Grade.** If the grade of each of the intersecting streets is 3% or less, as determined by calculating the rate between the established elevations, the elevation of the center lines of each street within the limits of the Curb Line Platform shall be the same as that fixed for the Center Line Intersection. The elevation of the curbs shall be determined as indicated in paragraph 8. Provided, however, that the difference in the elevation of points on the center lines opposite any building line corner shall not provide a greater transverse sidewalk slope than that fixed as the maximum in paragraph 7, in which latter event the Building Line Platform shall be used and the grades of that portion of the streets adjoining the said corners shall be flattened between the boundaries of the Building Line Platform and the Center Line Intersection, as provided in paragraph 5 (a).

"5. **Treatment of Platform for Streets Having a Steep Grade or Meeting at an Acute-Angled Intersection.** (a) If the grade of any portion or portions of intersecting streets adjoining a building line corner is over 3%, as calculated between the established elevations, or if a further flattening of the platform grade is required to provide proper sidewalk slopes for any part of an intersection described in paragraph 4, the grades of the said portion or portions of each street shall be reduced between the boundaries of the Building Line Platform and the Center Line Intersection as follows: If the intersecting streets are of the same width, the grade of the street traversing the shorter block length adjoining the intersection shall be reduced one-third and that of the street traversing the longer block shall be reduced two-thirds. In case the streets have different widths, the grade of the wider street shall be reduced one-third and that of the narrower street two-thirds between the above limits. All grades less than 3% which are not herein required to be flattened shall be applied at the same rate as originally computed between established elevations; provided, that in no case shall the maximum platform and sidewalk slopes fixed in paragraphs 6 and 7 be exceeded. Any excess in grade over that allowed in paragraph 7 shall be removed by further flattening, as follows: (b) Special flattening of platform grades for extreme cases of steep grades or acute angled intersections. If the difference in elevation tentatively fixed for points on the center lines of intersecting streets opposite any building line corner, after applying the minimum and up to the maximum transverse sidewalk slope on the higher and lower sides respectively, exceeds the maximum transverse sidewalk grades hereinbefore described, the elevation of each street at the boundary of the Building Line Platform shall be adjusted to remove the excess, the adjustment of each of the said elevations being directly proportional to the grade of each as originally flattened or applied. For all cases covered by paragraphs (a) and (b) the

elevations at the intersections of the center line of each of the narrower streets or at the streets traversing the longer blocks, if they are of equal width, with the Curb Line Platform of the intersected street shall be the same as the elevation of a point on the center line of the intersected street immediately opposite the first-named intersection, except that the elevation at this point shall be abandoned when the grade along the center line between the Curb Line Platform and the Building Line Platform exceeds the grade as originally computed. The grades of the center line of the wider street or of the street traversing the shorter block, if they are of equal width, shall be uniform between the exterior boundaries of the Building Line Platform and the Center Line Intersection, except that the maximum platform slope hereinafter fixed shall not be exceeded. The grades of the center line of the narrower street or of the street traversing the longer block, if they are of equal width, shall be uniform between the elevations fixed at the exterior boundaries of the Building Line Platform and those fixed at the boundaries of the Curb Line Platform, and also between the latter point and the Center Line Intersection.

"6. **Maximum Platform Grades.** The maximum allowable grade along the center line between the Curb Line Platform and the Center Line Intersection shall be at the rate of 4%, unless otherwise indicated on the map. The grades along the center line between elevations established within the limits of a Building Line Platform shall be uniform, subject only to the flattening provided for in paragraph 5 (b).

"7. Transverse Sidewalk Grades. Whenever practicable, the sidewalk shall slope upwards in a direction at right angles to the curb toward the building line at the rate of 2%. The elevation of the sidewalk at the building line corner shall be determined by applying this rate to the elevation of the curb, giving the higher building line elevation, at a point immediately opposite the corner, unless the resulting grade on the lower side exceeds 6%, in which case the sidewalk shall be level on the higher side and a greater transverse sidewalk slope up to the maximum shall be used on the lower side. The maximum transverse sidewalk slope shall be 6%, except in those cases where the street grade as originally computed on any street adjoining a building line corner is more than 6%, when the maximum slope shall be 10% for either street, opposite the said corner. In no case shall the sidewalk at the building line be lower than that of a point immediately opposite it on the curb. If the transverse sidewalk slope at the building line corner is more or less than 2%, it shall be made to agree with this latter rate at a point distant 25 ft from the building line corner.

"8. Curb Elevations. The relation between the elevation of the center lines and of the top of the curbs at points immediately opposite it at the boundary of and outwardly from the Building Line Platform shall be as follows: For roadway widths of 24 ft or less the top of the curbs shall be 0.1 ft higher than the center line. For roadway widths ranging from 24 ft up to and including 34 ft the top of the curbs and the center line shall be at the same elevation. For roadway widths ranging from 34 ft up to and including 44 ft the top of the curbs shall be 0.1 ft lower than the center line. For roadway widths ranging from 44 ft up to and including 54 ft the top of the curbs shall be 0.2 ft lower than the center line, and for roadway widths ranging from 54 ft up to and including 64 ft the top of the curbs shall be 0.3 ft lower than the center line. The elevation of the intersection of the curb tangents shall be determined from a point immediately opposite on the center line of the wider street or the street traversing the shorter block, if they are of equal width, subject, however, to the same correction in elevation between the top of the curbs and the center line as herein provided.

"9. Depth of Gutters. Whenever practicable a standard depth of gutter of 0.4 ft shall be used.

"10. Curb Grades at Corners. The tangents in the curbs shall be graded uniformly between the elevations established for them at the boundaries of the Building Line Platform and at the intersection of the curb tangents. The curve formed in the curb joining the tangents shall follow a uniform grade between the elevations of the curb tangents at the points of curve.

"11. Grades Between Platforms. The grades of the center line and of the curbs between the elevations computed at platform intersections, or between a platform and an intermediate established elevation, shall be uniform."

17. Roadway and Sidewalk Widths

Regulation by Ordinance. It is the usual practice of cities to fix by ordinance the roadway and sidewalk widths of all streets, and the roadway is usually given a width of approximately one-half the total street width, the remaining half being divided between the two sidewalks. In New York City this ordinance prescribes the following widths:

Street Width	Roadway Width
20 to 50 ft, not occupied by a railroad,	60% street width
50 to 60 ft, not occupied by a double-track railroad,	30 ft
60 to 66 ft 8 in, not occupied by a double-track railroad,	50% street width
66 ft 8 in, and over,	80% street width, less 20 ft

Standards for the subdivision of street widths are undoubtedly desirable rather than leaving these details to be fixed according to the whim of the developer or the notions of the engineer in each particular case, but the standards adopted have not often been the result of a careful study of the needs of traffic of various classes. One line of average vehicles under regulated traffic in an urban district requires for free movement about 8 ft of roadway width. Two lines in each direction, or one standing next the curb and the other moving, will therefore require 32 ft, altho 30 ft is generally sufficient for the purpose, and this should be the minimum width for business streets without surface railway tracks. Provision for an odd number of lines of traffic is not justified as the odd or middle line would be obliged to accommodate vehicles moving in both directions and the interference would be so great that it would be of little use. In case there are railway tracks in the street, special treatment will be necessary. A single-track railroad will use about 9 ft of width, and if provision is made on each side for a single line of vehicles in addition, whether standing at the curb or moving, at least 25 ft of roadway will be required. The New York City ordinances require not less than 30 ft where there is a single-track road, this allowing for exceptionally wide vehicles, such as moving vans, ice wagons or coal trucks standing at the curb without interfering with the free movement of cars. In the case of double-track railways, the space required for them is about 19 ft, and a single line of vehicles on each side would require a total width of at least 35 ft, and for two lines 51 ft. The New York ordinance requires not less than 40 ft where there are double-track railways.

Excess Widths of Roadways. While in nearly all cities there are some streets whose roadways are inadequate for the traffic which they attract, there are a far greater number where the roadways are much wider than required. This means a needless expense to the owners of the abutting property for the original improvement and a serious burden for the city in maintenance, repairs and renewals. Street traffic gradually increases as the abutting property is improved and the general business of the locality is increased. While it is wise to lay out streets of sufficient width to permit as intensive development of the adjoining property as the ordinances allow, there is no good reason for the laying and maintenance of an area of pavement which is obviously greater than will be required for

many years to come. A residential street 60 ft in width will not need a roadway 30 ft wide unless it is called upon to accommodate a considerable amount of thru traffic. Twenty feet or even less would in most cases be sufficient for the initial improvement. This saving of 10 ft in width will mean a substantial decrease in the burden of assessment for the first improvement, probably as much as $30 for each 25 ft of frontage. It may be that additional roadway width will not be required during the lifetime of the first pavement or even of two pavements, sometimes not at all. When more space is necessary the curb can be set back and the sewer inlets can be readjusted. When there is such a reduction in width, the street appurtenances back of the curb, such as lamp posts, fire hydrants and trees, can be so located as to conform with the ultimate position of the curb so that it may be set back with a minimum of expense and disturbance of existing conditions. Such a policy would save the property owners on a block 700 ft long about $1500 in the first cost of their pavement and the city would save a substantial sum annually for maintenance. When a widening is required, the cost of the additional pavement can properly be assessed upon the abutting property.

Sidewalks. It is impossible to estimate with any degree of accuracy the width of sidewalks which will be needed. In ordinary streets pedestrian traffic varies greatly with the weather and at different times of day, and in most cases there is an excess of sidewalk space which can advantageously be used for grass, trees and other planting, a stone, concrete or brick walk 4 or 5 ft wide being all that is required. In the case of retail shopping streets, however, more generous sidewalks are needed, while in such narrow thorofares as Hohe Strasse in Cologne and Kalver Straat in Amsterdam, the busiest shopping streets in these cities, the pedestrians use the roadways as well as the sidewalks, especially in the evenings. In the financial and office districts of London, New York and other large cities, the same use of the entire street by pedestrians is often seen and vehicular traffic is practically excluded at certain hours of the day. Where there is special need of sidewalk capacity on narrow streets, the roadway is sometimes reduced to a width which will accommodate but a single vehicle and the traffic in such streets is confined to a single direction. It is apparent, therefore, that no general principles as to the relative amount of roadway and sidewalk space required can be laid down.

18. Subdivision of Wide Streets

Exceptionally Wide Streets, of which there are some in every large city, present a special class of problems. It is impossible to formulate any but the most general principles by which plans for their subdivision should be governed. Not only do the conditions vary in each particular case, but there is a great opportunity for the exercise of personal judgment and taste. A discussion of the different conditions which may exist and the different ways in which the same problem may be solved will be of less value than a few examples of the treatment adopted for a number of wide streets in some of the great cities of the world. Such examples are shown in Fig. 20. The simple dignity of the Avenue des Champs-Élysées, 260 ft wide, with its single roadway 114 ft in width, renders it one of the most notable streets in the world, if it is not indeed the most notable. It was a daring treatment, however, which could only be successful in such a street with the spacious Place de la Concorde at one end and the

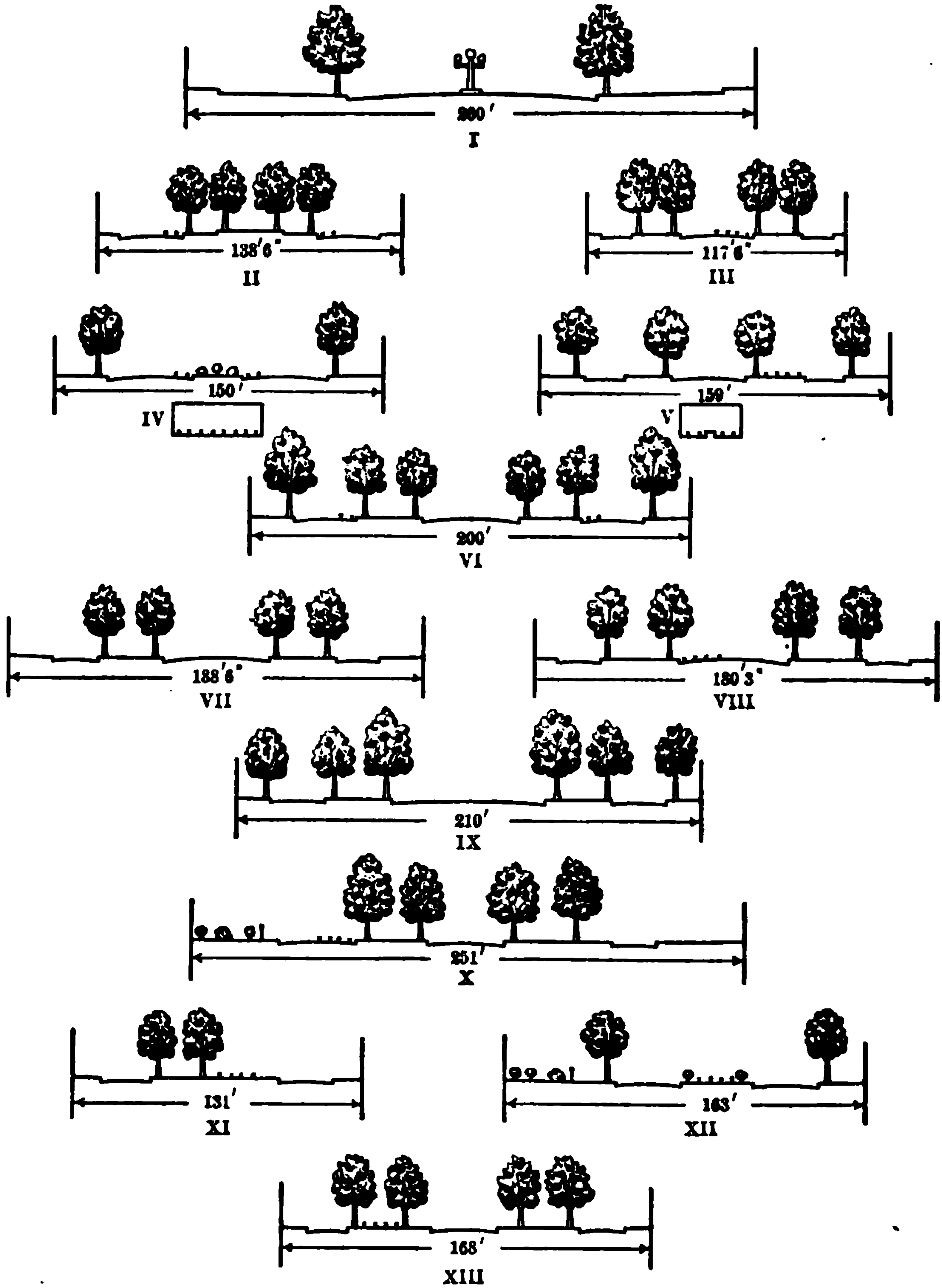

Fig. 20. Showing Instances of the Subdivision of Wide Streets in Various Cities

I. Avenue des Champs-Élysées, Paris
II. Stubel-Allee, Dresden
III. Adolfe-Allee, Wiesbaden, Germany
IV. Upper Broadway, New York City
V. Bismarck Strasse, Charlottenburg, Germany
VI. Queens Boulevard, New York City
VII. Ring Strasse, Vienna
VIII. Avenue Louise, Brussels
IX. Ocean Parkway, Brooklyn, N. Y.
X. Avenue de Tervueren, Brussels
XI. Kronprinzen Strasse, Mannheim, Germany
XII. Typical Boulevard, Berlin
XIII. Boulevard between Lille and Tourcoing, France

great Arc de Triomphe at the other. Streets of this exceptional width are usually divided into two or three roadways, one of which is commonly restricted to pleasure traffic.

Surface Railway Tracks are frequently located in streets of this kind and their position varies greatly, as will appear from the illustrations. While such tracks are sometimes placed in the wide roadway which is especially adapted to pleasure traffic, it is better to put them in the side roadways. Two tracks are in some cases placed in a single one of the side roadways, a serious objection to this arrangement being that while some of those wishing to use the surface cars may reach those going in both directions without crossing the central driveway, all who live on the other side of the wide street are obliged to cross the central and one side roadway in reaching or leaving cars going in either direction. Railway tracks are occasionally placed in one of the parking spaces, but it is difficult under such circumstances to maintain the grass in good condition, and the space used for this purpose is neither a successful parked area nor a simple railroad right-of-way. A conspicuously successful instance of this treatment is found in Bismarck Strasse, Charlottenburg, where between the municipally owned and operated surface railroad tracks excellent turf is maintained, and the space in which the tracks are located is edged with flowering plants, and for a portion of the distance by vines planted at intervals festooned to standards placed midway between them. Such success is so rare, however, as to render the plan an unsafe one to follow under the conditions which usually prevail, especially where the railway tracks are owned and operated not by the municipality but by public service corporations. An instance of an elevated railroad located in the central part of a very wide street with space for planting on each side of the structure is shown in Fig. 5.

REGULATIONS AND RESTRICTIONS

19. Traffic Regulations

In the Small City and Town the problem of traffic regulation is a simple one and the increase in the street use which occurs on certain days adds a certain amount of life and interest which is an agreeable change from the monotony of existence in a provincial community. As the town becomes a city and as the city continues to grow the increase in traffic results in congestion with its attendant delays and dangers. The time comes when the free and irresponsible movement of vehicles must give way to a certain degree of control, and intelligent police control has accomplished much in avoiding both danger and delay. Rules for traffic regulation are frequently resented when first imposed, but they are soon found to be for the best interests of both the public and the individual and are then accepted and respected. The problem to-day, as stated in the report for 1913 of the London Traffic Branch of the Board of Trade, is " to pass by artificial regulation thru existing streets of inadequate capacity, with safety to both passengers and pedestrians, a larger volume of traffic than the streets would accommodate were the movement of vehicles and pedestrians left uncontrolled." The electrically operated surface railway which has become so efficient a means of transportation in the streets, while carrying a greater number of passengers than any other vehicle, has preëmpted to its own use a considerable portion of the roadways and interferes very seriously with

free-wheeled vehicle traffic which the streets would otherwise be called upon to accommodate.

Street Traffic Increases in a much greater ratio than population. The report of the London Traffic Branch of the Board of Trade above referred to gives the increase in the number of passengers carried in 1913 over the number carried in 1903 as 50.1% by the underground railways, 102.2% by the surface railways, 91.9% by omnibuses, the total number of journeys per head, excluding those by trunk line railways, having increased 68.3%, while during the same period the population of greater London increased only 9%.

The Substitution of Motor for Horse-drawn Vehicles, resulting in greater speed, allows fewer vehicles to render the same service. This is strikingly shown by the traffic statistics of the London motor-buses. Of the increase in the number of passengers carried during the 10 years from 1903 to 1913, 66% took place from 1910 to 1912, the period during which the change in motive power occurred. But during these 10 years there was an actual decrease of 9.7% in the number of omnibuses operated. At the same time there has been a steady increase in the number passing certain points in busy streets. In Oxford Street between 6 and 7 P.M. the average interval between omnibuses in each direction decreased from 15½ sec in 1912 to 12½ sec in 1913, while in Piccadilly during the same hour the average interval decreased from 25½ sec in 1912 to 18 sec in 1913. While the above statistics relate to the city of London, they are typical of what is taking place in other great capitals, and the London figures have been used because this problem appears to have been the subject of more serious study in that city than elsewhere.

The Number of Accidents in the streets of a city will naturally vary with the density of traffic but they will also indicate the effectiveness of the methods employed for traffic regulation. From statistics compiled by the National Highway Protective Society and a British Parliamentary Committee appointed to study the subject, it appears that during the year 1911 the fatal accidents in the streets of the six largest cities of the world were as follows:

City	Fatal Accidents in 1911	Population	Fatal Accidents per 100 000 of Population
London	444	7 181 416	6.18
New York	423	4 766 883	8.87
Paris	236	2 763 393	8.54
Chicago	228	2 185 283	10.43
Berlin	143	2 101 933	6.80
Vienna	62	2 085 888	2.97

While London appears to lead all of these cities in the actual number of fatal accidents, when population is considered the streets of the London Metropolitan District appear to be safer than those of other cities of more than 2 000 000 population with the single exception of Vienna. The risk of accident appears greatest in Chicago, with New York second, and both of the American cities have a greater proportion of fatalities charged against them than the four cities of Europe, altho Paris is very little behind New York in this respect.

Block System. Traffic regulation has the two-fold purpose of facilitating movement and avoiding accident. The simplest and most common method of regulation is what is known as the block system under which all traffic at important crossings is periodically halted in order to allow that on the cross streets to proceed. When the blocks are very short and each crossing is regulated independently of the others there are still very annoying delays, passage across one street being frequently permitted just in time to allow the travel to be stopped at the crossing of the next street. An attempt has lately been made on Fifth Avenue, New York City, to treat about ten blocks or half a mile as a unit. A police officer is stationed at each of the cross streets. One of these streets will be of such importance that it should control the movement on the others. When the avenue traffic is halted at the controlling street a signal is at once transmitted to the other street crossings within the larger unit of control and the same halt is imposed at every crossing, so that there is free movement across the avenue at all of the ten streets simultaneously. When the delayed vehicles at the controlling cross street have been passed another signal is transmitted and there is free movement along the avenue for half a mile. While this plan has not been given a very extensive trial, it promises to result in freer movement for vehicles.

Fig. 21. Columbus Circle, New York City

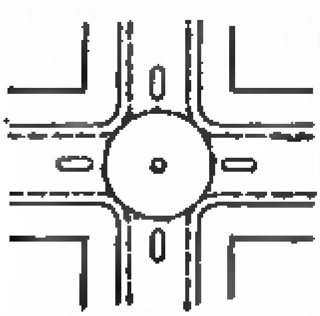

Fig. 22

Gyratory System. At important junctions where there is an enlargement of the street area, and especially where there is a circular space, the gyratory system is frequently adopted. This is strongly advocated by William Phelps Eno, who argues that it is capable of a much wider use and is even adaptable to right-angled crossings, where it would do away with the delays inseparable from the block system. An illustration of the application of the gyratory system to vehicular traffic is furnished by Columbus Circle, New York, Fig. 21, while Fig. 22 illustrates its proposed application to right-angled crossings of two streets 100 ft in width with refuges in each of the streets and a circular refuge at the intersection of

the center lines upon which a policeman could be stationed. Further information upon this subject will be found in the paper presented by Eno at the Third International Road Congress held in London in 1913.

20. Isles of Safety

Advantages and Disadvantages. Isles of safety are designed primarily as refuges for pedestrians crossing busy streets, affording them an opportunity after crossing the line of traffic of vehicles moving in one direction to stop and look before crossing the part of the roadway in which the movement is in the opposite direction. Such refuges are in general use in London, Paris, and other European cities, but much less frequently found in those of the United States. It is generally admitted that they offer some obstruction to vehicular traffic, but in European cities they are considered essential to safety. Subways for pedestrians have been built at busy crossings, notably at the Bank of London where the underground passage extends entirely around the junction of the several streets with entrances for each street and connections with the underground railway stations; but such subways are not very generally used, the public apparently being willing to take the risk of crossing busy thorofares on the surface rather than use the stairs leading to underground or overhead crossings. The location of lamp-posts or central standards supporting overhead trolley wires may, when placed short distances apart, offer a certain degree of protection to pedestrians crossing the streets, but they are considered so serious an obstruction to traffic that they are generally condemned, altho lamp standards of an ornamental design are frequently found in the centers of isles of safety, especially in European cities. Vehicles sometimes strike these refuge platforms and even mount them, to the great danger of pedestrians who may be occupying them—and in order to prevent accidents from this cause substantial stone or iron protection posts are frequently placed at the ends and sometimes also at the sides of these islands. It is frequently urged that center refuges serve a useful purpose in the control of vehicular traffic, performing a function somewhat similar to the subdivision of wide streets into several roadways, each limited to traffic moving in a single direction. Where the traffic movement is fairly uniform in both directions at all times of the day this is doubtless true, as they tend to keep the vehicles in line, but where there is a preponderance of movement in one direction at certain hours and in the opposite direction at other hours the roadway capacity is seriously curtailed. If the movement in one direction is double that in the other, two-thirds of the roadway can readily be devoted to vehicles moving in one direction, and when the tide turns this division between lines of traffic will automatically be moved to the other side of the street axis. The isle of safety is considered an essential feature of the gyratory system of traffic regulation as applied to crossings which are right-angled or nearly so, as illustrated by Fig. 22. While the introduction of islands of safety at rectangular intersections of streets of ordinary width may offer some obstruction to traffic, they are of unquestionable advantage in large open spaces where the street junctions are irregular. In their absence it is common practice to rope off certain areas within which vehicular traffic is not permitted. The protection thus afforded to pedestrians might be even more effective if these areas were converted into raised islands of refuge, altho the use of temporary standards connected by ropes has one advantage, namely, that

they can be removed or the space enclosed by them may be extended or curtailed at times when the character of the traffic at such junctions is materially changed.

21. The Effect of the Motor Vehicle upon the Street Plan

With the Increase in the Use of the Motor Vehicle new problems have been presented in street planning by reason of the great increase in the number ot vehicles, the increase in the size and wheel loads of motor trucks and the need of providing parking spaces for vehicles left standing in the streets.

Parking of Motor Vehicles. The greater speed and flexibility of the motor vehicle has greatly increased the capacity of streets so far as traffic movement is concerned, but the parking of motor cars along the curb, whether parallel therewith or at right angles thereto or in the center of the roadway where its width is sufficient, has reduced the available space for moving traffic, and in many cases roadways have had to be widened at the expense of the sidewalks. As the character of the street surface is generally improved motor traffic will become more diffused and the problem so far as moving vehicles are concerned will tend to solve itself, but the increasing size of the motor truck presents a serious problem.

Influence of Width and Length of Motor Vehicles. If a street has been designed to accommodate four lines of traffic and if, by reason of the increase in the width of vehicles, only three lines of traffic can be accommodated, the traffic capacity of the street is reduced by much more than one-fourth for the reason that the central space must be occupied by vehicles moving in both directions and the resulting interference will render it of relatively little use. Motor trucks as now constructed frequently carry on the rear axle more than 20 000 lb, including the weights of both vehicle and load. With solid rubber tires the load per inch width of tire reaches 800 lb and this limit is probably due to the inability of such tires to sustain any heavier load. The width of such trucks has increased to 8 ft in many cases, while the width of special loads, such as plate glass carried flat, may be still greater. The over-all length in some cases is as much as 28 ft, and there is a disposition to use trailers where the highway regulations will permit. As trailers are now so designed that they will closely follow the tractor and will not cut the corners in making turns, some manufacturers of motor trucks have expressed the opinion that the total length of tractor and trailers may reach 50 ft. The use of vehicles of this size on streets devoted to mixed traffic is likely to result in confusion, delay and danger, while it also will necessitate the readjustment of curb corners by increasing their radius.

Economic Loads and Speeds. The manufacturers of commercial motor vehicles are naturally disposed to produce those which will give the most efficient results by reducing the ton-mile cost of moving their loads. If this can be accomplished by increasing the loads, the speed or the dimensions of the vehicles they are likely to assume that roadway conditions will be adapted to the vehicles. The cost of such adaptation would involve great expense, which the public will scarcely be willing to assume. It is necessary, therefore, that the manufacturers devote more attention to the problem of adapting vehicles to existing conditions. Pavement crusts and their foundations can so be strengthened as to carry greater wheel loads at relatively little increased expense, but the widening of streets and road-

ways will be so costly as to be out of the question. Fortunately, the makers of motor trucks appear to have reached the conclusion that the cost per ton-mile of moving their loads is lowest in the case of a 5-ton truck at a speed of 9 miles an hr, or a 6-ton truck at 7 miles an hr, the cost increasing both in the case of lighter loads at higher speeds and in that of heavier loads at lower speeds.

Pennsylvania Regulations. There is need also of the adoption by municipal, county and state authorities of regulations restricting the width and wheel loads of vehicles as well as their speed. The State of Pennsylvania in 1913 enacted the following law, which, however, appears to permit a width which, if used to any great extent, may seriously restrict the capacity of city streets: " No motor vehicle shall be registerable which shall exceed 90 in outside, over-all width of vehicle and load combined, except that motor-buses for carrying passengers, to be used within the city limits only, in cities of the first, second and third classes, may be registered up to 100 in outside, over-all width of vehicle and load combined; or shall exceed a maximum of 24 000 lb, gross weight of vehicle and load combined; or shall exceed 18 000 lb, maximum gross weight of vehicle and load combined upon any axle; or shall exceed 750 lb, maximum gross weight of vehicle and load combined upon any one wheel, for each nominal inch of width of solid tire upon the wheel."

22. Encroachments upon Streets

The Obstruction of Public Highways is very common. There is a natural disposition to convert public property to private use where such action is tolerated, and the most frequent instance of such use is the conversion of that part of the sidewalk which does not seem to be needed by pedestrians at the time to the convenient or profitable use of the abutting owner. The exposure of goods for sale on the sidewalks in front of shops, the loading and unloading of bulky packages and barrels by means of skids extending across the sidewalks with complete interruption of their intended use, the erection of permanent platforms on the parts of the sidewalks in front of shops and warehouses handling heavy materials, the erection of storm doors, porches, steps to floors both above and below the street level, and even the storage of trucks and machinery in the streets at night, are not uncommon sights in many cities, whether the title to these streets is simply a public easement for street purposes or whether it is a fee absolute held in trust for the use and benefit of the whole city. In New York the practice of encroaching upon streets by steps, porches, show-windows, entrances, and even by supporting columns forming an integral part of the building structure, has become so common that the abutting owners have come to consider them entirely lawful and efforts to remove them are likely to be resisted as an invasion of their fully established rights.

The Case of Fifth Avenue in New York is a conspicuous but typical instance of this practice. This avenue was laid out and acquired at a width of 100 ft. The roadway was 40 ft wide with sidewalks of 30 ft on each side, but half of the sidewalk space had for many years been converted to private use. Many costly buildings had been erected along the avenue whose entrances, steps, bay-windows and in many cases supporting columns and pilasters extended beyond the street lines. Fences had been erected enclosing one-half the sidewalk, and in some cases sunken gardens and ornamental planting occupied the space inside of these fences or low

walls. So long as the street remained devoted to high-class residences these encroachments excited little comment or criticism, but when the street was given over chiefly to business and the vehicular traffic was greatly increased, the roadway of 40 ft became inadequate and it was widened to 55 ft with sidewalks 22½ ft in width on each side. The opposition to the removal of these obstructions, which was done at the entire expense of the abutting owners, was less than had been anticipated, and the change was found to be so beneficial, not only to the general public but to the occupants of the shops, that the same course has been followed in many other streets.

American and European Cities. The conditions in New York are typical of those found in other American cities and which frequently prevail in those of Europe where such encroachments are sometimes maintained by private owners and not infrequently by the city itself, altho investigation would probably show that they have existed for generations and have not been erected in violation of public rights which may have been acquired and paid for by the city. The recovery of this space for the public use for which it was designed is naturally the first step to be taken to increase the capacity of public streets which have become congested, the space so recovered being added to the roadway where necessary or divided between the roadway and sidewalks. The best way to avoid the difficulty and annoyance of this procedure is not to allow such conditions to come about. If there is more space within the street lines than is needed for vehicular and pedestrian traffic for the time being, that is no reason why the appropria[illegible] of any portion of it to private use should be permitted. If the r[illegible] and sidewalks are temporarily treated as described in Art. 17, [illegible]nt to the increasing needs of traffic can be accomplished with a [illegible] of annoyance and expense.

23. Set-Back Restrictions

[illegible]ding Lines Back of Street Lines. In some cities building lines are [illegible]ablished which are a certain distance back of the actual street lines, but this is really the taking of private property for public use which is generally forbidden by statute or constitution unless compensation be made. The Liverpool Corporation Act of 1908 provides that it shall not be lawful to erect in any street any building or part of a building until the building line for such street has been approved by the Corporation, nor beyond nor in front of a building line so approved. The building line does not mean the street line, but it may be coincident with such street line or a certain distance back of it. If the Corporation requires as a condition of its approval of any plan the setting back of the building line to a greater distance from the street line than one-tenth of the prescribed width of the street, the Corporation shall make compensation to the owner of any land lying between such one-tenth and the building line which may be established for any damage sustained by him by reason of his being unable to build upon the land. This means that while the municipal authorities may forbid the use of a strip of private property equal to one-tenth the width of the street without compensation, it must compensate the owner if it forbids him to build upon any portion of his lot in addition to a strip of frontage equal in depth to one-tenth the width of the street. While laws of this kind would almost invariably be contested in the United States, many real estate developers impose set-back restrictions for a term of

years, seldom more than 25 years, and the purchasers welcome such restrictions as giving a certain distinction to the neighborhood, and they actually enhance the value of the property for residential purposes, especially where the houses are detached and each dwelling is required to occupy a plot having not less than a specified frontage. As in the course of time the character of the district changes and the property becomes so valuable that detached houses are too expensive a luxury for the average owner, these set-back restrictions depreciate values, as they may prevent a more intensive development by the erection of apartment houses requiring the full depth of the plots. Consequently, when such restrictions expire they are not likely to be renewed unless the character of the neighborhood remains unchanged or the property has not, as a result of improved transit with greater accessibility and the greater development of the contiguous districts, become too valuable for continued use for detached houses. If such restrictions could be permanently maintained, the problem of street widening to provide additional traffic capacity would be greatly simplified.

In Some Cities the Widening of Old Streets is accomplished by progressively setting back the building line, this being accomplished by a provision that all new buildings which are erected or all old buildings which are remodeled must conform with a new line some distance back of the former street line, the property thus relinquished to public use being acquired and paid for at the time of the change. This plan has the advantage of allowing the expense of the change to be spread over a number of years and avoiding the element of building damage, but there is the disadvantage of a ragged and unsightly street line during the period of transformation and it would in most cases be thought better to do the work at once and have it over with than allow it to be carried over a long term of years. Some of the expensive street widenings in Paris and other European cities have been accomplished in this progressive manner but it is rarely if ever adopted by American cities.

Restrictions Imposed by Private Developers. In the case of private developments where streets have been laid out in advance of the adoption of a final plan and the buildings have been set back under restrictions imposed by the developer, it is frequently thought best, when making the final plan, to give the street a more generous width, which could often be done without any damage to buildings. This, however, is likely to meet with objection on the part of the owners who regard as their own property the space between their houses and the alleged street line according to which they bought, even tho they have made no use of it and cannot use it during the term covered by the life of the restrictions. In such cases these objections to the proposed new street lines may be overcome by an agreement on the part of the city that the roadway, which is in most instances not yet paved, may be considerably reduced in width, resulting in a much smaller assessment for paving.

24. Arrangement of Buildings

The Regulation of the Proportion of Building Plots which may be occupied is now considered a proper exercise of municipal authority as it is essential to good sanitation and a reasonable supply of light and air, and their existence or non-existence will greatly influence the design of the street system. Such regulations vary greatly in different countries and in the different cities of the same country.

Foreign Practice. The most stringent and specific are those of German cities, several examples of which will be given. In Berlin the proportion of any lot which may be built upon depends upon the area of the lot and its location. For all lots up to 32 m (105 ft) in depth the regulations are similar for all portions of the city, both within and without the former walls; for the purpose of computing the portion which may be built upon, the lot is divided into strips or zones, the first of which extends from the building line to a depth of 6 m (20 ft), the second from the 6-m line to a depth of 32 m (105 ft) from the building line. On the first strip the entire area may be covered; on the second strip 70% of the area may be covered, while if the lot is deeper than 32 m (105 ft) 60% of the area back of the 32-m (105-ft) line may be built upon if it lies inside the former city walls and five-tenths if without the old walls. In computing the area which may be occupied, the areas upon which building is permitted on the different strips are added together and the resulting total area may be occupied by buildings without regard to the proportion so occupied on any one of the strips.

Fig. 23. Typical Plan Showing the Regulations Governing Character of Buildings and the Purposes for which They may be Used which are Imposed upon Specific Areas by the City of Leipzig

In Düsseldorf there are five zones with several classes in each for which the proportion of the lot which may be built upon is prescribed. In zone one there are three classes, in one of which 66.7% of the lot may be covered, in another 50% if there are rear buildings, and in the third 75%, provided the buildings are not more than 10 m (33 ft) or two stories in height. In the second zone there are also three classes, in one of which 50% of the lots may be covered by buildings, in another 40% if there are rear buildings, and in the third 60% for buildings accommodating from one to four families and even more than four familes if there are not more than two apartments on each floor. The third, fourth and fifth zones have two,

five and three classes respectively, the proportion of the lots which may be covered being gradually decreased until in some cases not more than 30% of the lot may be built upon. The detail with which regulations of this kind are prescribed by the German cities is illustrated by Fig. 23, showing those applying to a restricted area in the city of Leipzig.

In GREAT BRITAIN such regulations are less precise and there is a greater similarity between those in force in different cities. In Birmingham, for example, the regulations provide that all new buildings shall be so erected as to leave in the rear an open space having an aggregate area of not less than 300 sq ft which shall be free from any structure above the ground level except water-closets, earth-closets or ash-pits.

American Practice. In the United States some cities have more drastic regulations than others, but in no cases have they been worked out in such great detail as in Germany. The laws and ordinances governing open spaces are found in building codes, health regulations, factory and labor laws, and the city ordinances.

In NEW YORK, dwelling houses accommodating not more than two families may cover 90% of the lot; hotels may occupy 90% of interior and 95% of corner lots above the second floor, but for each and every story over five an additional 2.5% of the lot must be left free, so that at the fifteenth floor 35% of interior and 30% of corner lots must be left open; office buildings located on interior lots may cover 90% of the lots, while on corner lots having an area of 3000 sq ft or less they may cover the entire lot; tenement houses accommodating three or more families may cover 90% of corner lots having an area of not more than 3000 sq ft, but on interior lots 30% of the space must remain open.

In CHICAGO, tenement houses may not be built nearer than 10 ft to the rear lot line, except that when the lot abuts upon a public alley the rear line of the building may be within 16 ft of the opposite side of the alley. Rear buildings may be erected on a lot only on condition that the minimum distance between front and rear buildings is 10 ft and that neither building exceeds one story in height, an additional 5 ft being added to the minimum distance for every story more than one of the higher building on the lot, provided that a one-story building not used for habitation may be placed on the rear of a lot containing a tenement house if a minimum distance of 10 ft between the buildings is maintained at every point.

In PHILADELPHIA, the only regulation is that no building for dwelling purposes shall have a frontage of less than 14 ft and that at least 144 sq ft of the lot shall be left open.

BOSTON requires that where tenement houses have no open space on either side they must have a yard the full width of the building at least 12 ft in depth in the rear and the building must not exceed 1800 sq ft in area.

25. Height Limitations

Legal Restrictions. While the need of regulations governing the arrangement of buildings and the amount of space which must be left open are so obvious that they are not likely to be opposed, those which are designed to limit the height of buildings are not always accepted as reasonable. The erection of office buildings to any height which the owner finds practicable has been carried so far that a serious situation has been created. When built in close proximity to each other they not only rob their neighbors of light and air and darken the streets, but the congestion in the adjoining

streets greatly interferes with free movement. American cities are just beginning to realize the seriousness of this problem and efforts are being made to solve it. Either the street must be widened or the height of buildings must be limited. Street widenings after the erection of tall and costly buildings involve prohibitive expense, and the only feasible remedy appears to be the imposition of reasonable height limitations before it is too late.

Foreign Practice. Berlin limits the height of buildings to the width of the street upon which they front measured between the building lines, but there is a general regulation that the fronts of no buildings for habitation may exceed five stories in height altho the roof may be carried to a greater height provided no part of it projects beyond a line drawn at 45° back from the top of the front wall. In the case of rear buildings or those fronting upon inside courts, which are too common in this and other German cities, the limits of height are governed by the dimensions of the court, but the height may not exceed by more than 6 m (20 ft) the width of the court on which they front, and in no case may it exceed 22 m (72 ft).

Düsseldorf prescribes the following height limitations for each of the five zones referred to in Art. 24: Zone one, 20 m (66 ft); zones two and three, 16 m (52 ft) or, where four stories are allowed, 20 m (66 ft); zone four, 16 m (52 ft); zone five, 13 m (43 ft) or, where three stories are allowed, 16 m (52 ft). In none of the zones, however, may the height of buildings exceed the width of the streets upon which they abut.

Birmingham prohibits the erection of any building to a greater height than 100 ft, and, while Liverpool restricts the height of dwellings erected in new streets to the width of the street between opposite buildings, there is no limit to the height to which business buildings may be carried.

American Practice. In the United States the regulations respecting permissible heights of buildings vary greatly, and in most places the permissible height is so great as to present no real limitation. In New York, while the tenement house and other special laws imposed a virtual limit upon the height of certain classes of buildings, there was, prior to July 25, 1916, no direct limit prescribed by statute or ordinance except that which restricted buildings used as dwellings to a height of one and a half times the width of the widest abutting streets. Office buildings could be carried to any height, the tallest building of this class yet erected being 752 ft above the street level.

In Chicago, tenements or dwelling houses may not exceed by more than one-half the width of the widest street on which they front, buildings which are set back from the street line being allowed to add the amount of such set-back to the street width in computing the allowable height. Fire-proof office and business buildings may be carried to a height of 200 ft above the sidewalk, this limit having been reduced from 260 ft on September 1, 1911. Philadelphia imposes no restrictions whatever upon building heights. In Boston, buildings in the business section may not exceed two and one-half times the street width and in no case may be more than 125 ft high. In other parts of the city the limit is 80 ft, except where but one side of the street is built upon or where a street is 80 ft or more in width, when the height may be 100 ft.

Washington imposes a height limit of 160 ft for buildings on Pennsylvania Avenue; 20 ft more than the street width on other business streets, with a flat limit of 130 ft; 85 ft on residential streets, provided that on streets over 70 ft wide the height may not exceed the street width minus

10 ft; 60 ft on streets from 60 to 70 ft wide, and the street width where that width is less than 60 ft.

Charleston, New Orleans, Cleveland and Fort Wayne restrict building heights to two and one-half times the width of the widest street with absolute limits of 125 ft in Charleston, 160 ft in New Orleans, and 200 ft in Cleveland and Fort Wayne. Buffalo and Rochester limit the height to four times the average least dimension of the building without specific limit in feet, while Toronto permits a height of five times the least dimension with an absolute limit of 130 ft.

New York City Limitations, 1916. On July 25, 1916, the Board of Estimate and Apportionment of the City of New York adopted a comprehensive plan for the regulation of building heights. These regulations were recommended by a commission created for the purpose, and were presented after thoro study and many public hearings, and were almost unanimously approved by all of the interests represented at the hearings. The regulations contained in Art. III, " Height Districts," are as follows:

"**Height Districts.** For the purpose of regulating and limiting the height and bulk of buildings hereafter erected, the City of New York is hereby divided into five classes of districts: (1) One times districts, (2) one and one-quarter times districts, (3) one and one-half times districts, (4) two times districts, (5) two and one-half times districts; as shown on the height district map which accompanies this resolution and is hereby declared to be part hereof. The height districts designated on said map are hereby established. The height district map designations and map designation rules which accompany said height district map are hereby declared to be part thereof. No building or part of a building shall be erected except in conformity with the regulations herein prescribed for the height district in which such building is located.

1. In a one times district no building shall be erected to a height in excess of the width of the street, but for each 1 ft that the building or a portion of it sets back from the street line 2 feet shall be added to the height limit of such building or such portion thereof.

2. In a one and one-quarter times district no building shall be erected to a height in excess of one and one-quarter times the width of the street, but for each 1 ft that the building or a portion of it sets back from the street line 2½ ft shall be added to the height limit of such building or such portion thereof.

3. In a one and one-half times district no building shall be erected to a height in excess of one and one-half times the width of the street, but for each 1 ft that the building or a portion of it sets back from the street line 3 ft shall be added to the height limit of such building or such portion thereof.

4. In a two times district no building shall be erected to a height in excess of twice the width of the street, but for each 1 ft that the building or a portion of it sets back from the street line 4 ft shall be added to the height limit of such building or such portion thereof.

5. In a two and one-half times district no building shall be erected to a height in excess of two and one-half times the width of the street, but for each 1 ft that the building or a portion of it sets back from the street line 5 ft shall be added to the height limit of such building or such portion thereof.

"**Height District Exceptions.** 1. On streets less than 50 ft in width the same height regulations shall be applied as on streets 50 ft in width and, except for the purposes of paragraph 4 of this section, on streets more than 100 ft in width the same height regulations shall be applied as on streets 100 ft in width.

2. Along a narrower street near its intersection with a wider street, any building or any part of any building fronting on the narrower street within 100 ft, measured at right angles to the side of the wider street, shall be governed by the height regulations provided for the wider street. A corner building on such intersecting streets shall be governed by the height regulations provided for the wider street for 150 ft from the side of such wider street, measured along such narrower street.

3. Above the height limit at any level for any part of a building a dormer, elevator bulkhead or other structure may be erected provided its frontage length on any given

street be not greater than 60% of the length of such street frontage of such part of the building. Such frontage length of such structure at any given level shall be decreased by an amount equal to 1% of such street frontage of such part of the building for every foot such level is above such height limit. If there are more than one such structure, their aggregate frontage shall not exceed the frontage length above permitted at any given level.

4. If the area of the building is reduced so that above a given level it covers in the aggregate not more than 25% of the area of the lot, the building above such level shall be excepted from the foregoing provisions of this article. Such portion of the building may be erected to any height, provided that the distance which it sets back from the street line on each street on which it faces, plus half of the width of the street, equals at least 75 ft. But for each 1% of the width of the lot on the street line that such street wall is less in length than such width of the lot, such wall may be erected 4 in nearer to the street line.

5. When at the time plans are filed for the erection of a building there are buildings in excess of the height limits herein provided within 50 ft of either end of the street frontage of the proposed building or directly opposite such building across the street, the height to which the street wall of the proposed building may rise shall be increased by an amount not greater than the average excess height of the walls on the street line within 50 ft of either end of the street frontage of the proposed building and at right angles to the street frontage of the proposed building on the opposite side of the street. The average amount of such excess height shall be computed by adding together the excess heights above the prescribed height limit for the street frontage in question of all of the walls on the street line of the buildings and parts of buildings within the above defined frontage and dividing the sum by the total number of buildings and vacant plots within such frontage.

6. Nothing in this article shall prevent the projection of a cornice beyond the street wall to an extent not exceeding 5% of the width of the street nor more than 5 ft in any case. Nothing in this article shall prevent the erection above the height limit of a parapet wall or cornice solely for ornament and without windows extending above such height limit not more than 5% of such height limit, but such parapet wall or cornice may in any case be at least 5½ ft high above such height limit.

7. The provisions of this article shall not apply to the erection of church spires, belfries, chimneys, flues, or gas holders.

8. Where not more than 50 ft of a street frontage would otherwise be subjected to a height limit lower than that allowed immediately beyond both ends of such frontage, the height limit on such frontage shall be equal to the lesser of such greater height limits.

9. If an additional story or stories are added to a building existing at the time of the passage of this resolution, the existing walls of which are in excess of the height limits prescribed in this article, the height limits for such additional story or stories shall be computed from the top of the existing walls as tho the latter were not in excess of the prescribed height limits and the carrying up of existing elevator and stair enclosures shall be exempted from the provisions of this article."

26. Restrictions as to the Use of Property

The existence of regulations respecting the uses to which property may be put and the establishment of districts within which certain activities shall be confined will control to a large degree the arrangement of the streets and the block dimensions in the different parts of a city.

Foreign Practice. In this respect, also, the German cities have gone further than have those of other countries in their efforts to define the character of different districts and to maintain that character when established. The factory districts are naturally located along the lines of rail or water transportation, but their position with respect to the remainder of the city is often determined by the direction of the prevailing winds, in order that smoke and odors may not become a nuisance in the business and residential districts.

American Practice. A number of American cities have adopted district regulations, but none of them have gone as far in this respect as Los Angeles. By an ordinance enacted in 1909 this entire city, with the exception of two suburbs, is divided into industrial and residential districts, there being 25 of the former and but one of the latter. The industrial districts are widely scattered and the residential district includes the remaining area so that it entirely surrounds many of the industrial districts and really covers the entire city with limited areas taken out here and there. Provision is also made for residence exceptions within the residential district where business is permitted subject to certain conditions, and 58 of these exceptions have been designated. The industrial districts vary greatly in size and shape, the largest including an area of several square miles and the smallest a single lot. They are generally confined to one part of the city and their combined area is about one-tenth that of the residential district. Seattle adopted a building code in 1913 which imposes restrictions upon the use to which property within the city may be put, while the State Legislature of Maryland has regulated the use of property within certain parts of Baltimore. The State of New York in 1913 authorized the municipal legislative body in any city of the second class, on petition of two-thirds of the property owners affected, to establish residential districts within which no buildings other than single or two-family dwellings may be erected. In 1912 the Massachusetts Legislature gave authority to any city or town in the State, except Boston, which was covered by special acts, to regulate the height, area and location and use of buildings and other structures within the whole or any defined part of its limits, excepting, however, bridges, wharves and structures under control of and occupied by the National or State Government. Minnesota has authorized the cities of Minneapolis, St. Paul and Duluth to establish residential and industrial districts by a two-thirds vote of the municipal legislative bodies, and Wisconsin has conferred similar powers upon eight of the principal cities of the State. The Provincial Legislature of Ontario has authorized the councils of cities of more than 100 000 population to restrict the erection of buildings to certain classes in designated parts of the city, and Toronto, acting under this authority, has prescribed the use to which property may be put in a considerable portion of the city.

New York City Restrictions, 1916. The most recent regulations affecting the use of property are those adopted by the Board of Estimate and Apportionment of the City of New York on July 25, 1916, as part of the general scheme of building and use regulations referred to in the preceding Article. The use restrictions are indicated by a map covering the entire City, upon which is designated the use to which property abutting on every street in the City may be put. The general regulations contained in Art. II, " Use Districts," are as follows:

" **Use Districts.** For the purpose of regulating and restricting the location of trades and industries and the location of buildings designed for specified uses, the City of New York is hereby divided into three classes of districts: (1) Residence districts, (2) business districts, and (3) unrestricted districts; as shown on the use district map which accompanies this resolution and is hereby declared to be part hereof. The use districts designated on said map are hereby established. The use district map designations and map designation rules which accompany said use district map are hereby declared to be part thereof. No building or premises shall be erected or used for any purpose other than a purpose permitted in the use district in which such building or premises is located.

" **Residence Districts.** In a residence district no building shall be erected other than a building, with its usual accessories, arranged, intended or designed exclusively

for one or more of the following specified uses: (1) Dwellings, which shall include dwellings for one or more families, and boarding houses, and also hotels which have 30 or more sleeping rooms; (2) clubs, excepting clubs the chief activity of which is a service customarily carried on as a business; (3) churches; (4) schools, libraries or public museums; (5) philanthropic or eleemosynary uses or institutions, other than correctional institutions; (6) hospitals and sanitariums; (7) railroad passenger stations; (8) farming, truck gardening, nurseries or greenhouses.

"In a residence district no building or premises shall be used for any use other than a use above specified for which buildings may be erected and for the accessory uses customarily incident thereto. The term accessory use shall not include a business nor shall it include any building or use not located on the same lot with the building or use to which it is accessory. A private garage for more than five motor vehicles shall not be deemed an accessory use.

"Business Districts. 1. In a business district no building or premises shall be used, and no building shall be erected which is arranged, intended or designed to be used, for any of the following specified trades, industries or uses: Ammonia, chlorine or bleaching powder manufacture; asphalt manufacture or refining; assaying, other than gold or silver; blacksmithing or horseshoeing; boiler making; brewing or distilling of liquors; carpet cleaning; celluloid manufacture; crematory; distillation of coal, wood or bones; dyeing or dry cleaning; electric central station power plant; fat rendering; fertilizer manufacture; garage for more than five motor vehicles, not including a warehouse where motor vehicles are received for dead storage only, and not including a salesroom where motor vehicles are kept for sale or for demonstration purposes only; gas, illuminating or heating, manufacture or storage; glue, size and gelatine manufacture; incineration or reduction of garbage, offal, dead animals or refuse; iron, steel, brass or copper works; junk, scrap paper or rag storage or baling; lamp-black manufacture; lime, cement or plaster of Paris manufacture; milk bottling and distributing station; oilcloth or linoleum manufacture; paint, oil varnish or turpentine manufacture; petroleum refining or storage; printing ink manufacture; raw hides or skins, storage, curing or tanning; repair shop for motor vehicles; rubber manufacture from the crude material; saw or planing mill; shoddy manufacture or wool scouring; slaughtering of animals; smelting; soap manufacture; stable for more than five horses; starch, glucose or dextrine manufacture; stock yards; stone or monumental works; sugar refining; sulphurous, sulphuric, nitric or hydrochloric acid manufacture; tallow, grease or lard manufacturing or refining; tar distillation or manufacture; tar roofing or tar waterproofing manufacture.

2. In a business district no building or premises shall be used, and no building shall be erected, which is arranged, intended or designed to be used for any trade, industry or use that is noxious or offensive by reason of the emission of odor, dust, smoke, gas or noise; but car barns or places of amusement shall not be excluded.

3. In a business district no building or premises shall be used, and no building shall be erected, which is arranged, intended or designed to be used for any kind of manufacturing, except that any kind of manufacturing not included within the prohibitions of paragraphs 1 and 2 of this section may be carried on provided not more than 25% of the total floor space of the building is so used, but space equal to the area of the lot may be so used in any case, altho in excess of said 25%. The printing of a newspaper shall not be deemed manufacturing. No use permitted in a residence district by section on 'Residence Districts' shall be excluded from a business district.

"Unrestricted Districts. The term 'unrestricted districts' is used to designate the districts for which no regulations or restrictions are provided by this article.

"Existing Buildings and Premises. In any building or premises any lawful use existing therein at the time of the passage of this resolution may be continued therein, altho not conforming to the regulations of the use district in which it is maintained, or such use may be changed or converted or extended thruout the building, provided, in either case, that no structural alterations, except as required by existing laws and ordinances, are made therein and no new building is erected, and provided further that: (1) In a residence district no building or premises unless now devoted to a use that is by section on 'Business Districts' prohibited in a business district, shall be converted to such use; and (2) in a residence or business district no building or premises unless now devoted to a use that is by paragraph 1 or 2 of section on 'Business Districts' prohibited in a business district shall be converted to such use.

"No existing building designed, arranged, intended or devoted to a use not permitted by this article in the district in which such use is located shall be enlarged, extended, reconstructed or structurally altered unless such use is changed to a use permitted in the district in which such building is located; except that such building may be reconstructed or structurally altered to an extent not greater than 50% of the value of the building, exclusive of foundations, for the purpose of continuing therein, without any extension thereof, a lawful use existing therein at the time of the passage of this resolution, and such use may be continued therein, altho not conforming to the regulations of the use district in which it is maintained.

"Use District Exceptions. The Board of Appeals, created by Chapter 503 of the Laws of 1916, may, in appropriate cases, after public notice and hearing, and subject to appropriate conditions and safeguards, determine and vary the application of the use district regulations herein established in harmony with their general purpose and intent as follows:

1. Permit the extension of an existing building and the existing use thereof upon the lot occupied by such building at the time of the passage of this resolution or permit the erection of an additional building upon a lot occupied at the time of the passage of this resolution by a commercial or industrial establishment and which additional building is a part of such establishment.

2. Where a use district boundary line divides a lot in a single ownership at the time of the passage of this resolution, permit a use authorized on either portion of such lot to extend to the entire lot, but not more than 25 ft beyond the boundary line of the district in which such use is authorized.

3. Permit the extension of a building into a more restricted district under such conditions as will safeguard the character of the more restricted district.

4. Permit in a residence district a central telephone exchange or any building or use in keeping with the uses expressly enumerated in section on 'Residence Districts' as the purposes for which buildings or premises may be erected or used in a residence district.

5. Permit in a business district the erection of a garage or stable in any portion of a street between two intersecting streets in which portion or block there exists a public garage or public stable at the time of the passage of this resolution.

6. Grant in undeveloped sections of the city temporary and conditional permits for not more than 2 years for structures and uses in contravention of the requirements of this article."

27. Zoning

Need of Zoning. No plan for the regulation of building heights, the uses to which property may be put, and the proportion of the plots which may be built upon can be intelligently worked out except under a zoning system. Regulations governing the height of buildings or the area which may be covered in office building, financial or industrial districts would be entirely inappropriate in residential or suburban districts, and it is only by the adoption of a system of zones that such restrictions can be appropriate and equitable and will have the effect of insuring the character of a neighborhood and stabilizing land values.

Plan Adopted by New York City in 1916. The zoning plan has been highly developed in German cities and is an essential feature of the general scheme of building regulation recently adopted by the City of New York as described in Arts. 25 and 26. While height restrictions are imposed according to districts or zones, these districts are not identical with those adopted for determining the proportion of the plots which may be built upon. The New York ordinance provides five different kinds of districts, and there are many districts of the same kind scattered over the City and separated from each other by districts of other classes. Art. IV of the ordinance dealing with area districts is as follows:

"Area Districts. For the purpose of regulating and determining the area of yards, courts and other open spaces for buildings hereafter erected, the City of New York

is hereby divided into five classes of area districts: A, B, C, D and E; as shown on the area district map which accompanies this resolution and is hereby declared to be part hereof. The area districts designated on said map are hereby established. The area district map designations and map designation rules which accompany said area district map are hereby declared to be a part thereof. No building or part of a building shall be erected except in conformity with the regulations herein prescribed for the area district in which such building is located. Unless otherwise expressly provided, the terms rear yard, side yard, outer court or inner court when used in this article shall be deemed to refer only to a rear yard, side yard, outer court or inner court required by this article. No lot area shall be so reduced or diminished that the yards, courts or open spaces shall be smaller than prescribed in this article.

"A DISTRICTS. In an A district a court at any given height shall be at least 1 in in least dimension for each 1 ft of such height.

"B DISTRICTS. In a B district a rear yard at any given height shall be at least 2 in in least dimension for each 1 ft of such height. The depth of a rear yard at its lowest level shall be at least 10% of the depth of the lot, but need not exceed 10 ft at such level. An outer court or a side yard at any given height shall be at least 1 in in least dimension for each 1 ft of such height. An outer court at any given point shall be at least 1½ in in least dimension for each 1 ft of length. But for each 1 ft that an outer court at any given height would, under the above rules, be wider in its least dimension for such height than the minimum required by its length, 1 in shall be deducted from the required least dimension for such height for each 24 ft of such height. A side yard for its length within 50 ft of the street may for the purposes of the above rule be considered an outer court.

"C DISTRICTS. 1. In a C district a rear yard at any given height shall be at least 3 in in least dimension for each 1 ft of such height. The depth of a rear yard at its lowest level shall be at least 10% of the depth of the lot but need not exceed 10 ft at such level. An outer court or a side yard at any given height shall be at least 1½ in in least dimension for each 1 ft of such height. An outer court at any given point shall be at least 1½ in in least dimension for each 1 ft of length. On a lot not more than 30 ft in mean width an outer court or a side yard at any given height shall be not less than 1 in in least dimension for each 1 ft of such height, and an inner court at any given height shall be either (1) not less than 2 in in least dimension for each 1 ft of such height or (2) it shall be of an equivalent area as hereinafter specified in paragraph 3 of section on 'Courts.'

2. If the owner or owners of any part of a C district set aside perpetually for the joint recreational use of the residents of such part designated by them an area at least equal to 10% of the area of such part in addition to all yard and court requirements for a B district, such part shall be subject to the regulations herein prescribed for a B district. Such joint recreational space shall be composed of one or more tracts, each of which shall be at least 40 ft in least dimension and 5000 sq ft in area and shall be approved by the Board of Appeals as suitable for the joint recreational use of such residents.

"D DISTRICTS. 1. In a D district a rear yard at any given height shall be at least 4 in in least dimension for each 1 ft of such height. The depth of a rear yard at its lowest level shall be at least 10% of the depth of the lot, but need not exceed 10 ft at such level. If a building in a D district is located in a residence district as designated on the use district map, the depth of a rear yard at its lowest level shall be at least 20% of the depth of the lot, but need not exceed 20 ft at such level. However, for each 1 ft in excess of 10 ft of the depth of such rear yard at its lowest level, there may be substituted 1 ft of depth of unoccupied space across the whole width of the front of the lot at the curb level between the street line and the street wall of the building.

2. In a D district an outer court or a side yard at any given height shall be at least 2 in in least dimension for each 1 ft of such height. An outer court at any given point shall be at least 2 in in least dimension for each 1 ft of length. On a lot not more than 30 ft in mean width an outer court or a side yard at any given height shall be not less than 1½ in in least dimension for each 1 ft of such height. On such lot an outer court at any given point shall be not less than 1½ in in least dimension for each 1 ft of length. On such lot an inner court at any given height shall be either (1) not less than 3 in in least dimension for each 1 ft of such height or (2) it shall be of an equivalent area as specified in paragraph 3 of section on 'Courts.'

3. In a D district no building located within a residence district as designated on the use district map shall occupy at the curb level more than 60% of the area of the lot if an interior lot or 80% if a corner lot. In computing such percentage any part of the area of any corner lot in excess of 8000 sq ft shall be considered an interior lot.

4. If the owner or owners of any part of a D district set aside perpetually for the joint recreational use of the residents of such part designated by them, an area at least equal to 10% of the area of such part in addition to all yard and court requirements for a C district, such part shall be subject to the regulations herein prescribed for a C district. Such joint recreational space shall be composed of one or more tracts each of which shall be at least 40 ft in least dimension and 5000 sq ft in area and shall be approved by the Board of Appeals as suitable for the joint recreational use of such residents.

"E Districts. 1. In an E district a rear yard at any given height shall be at least 5 in in least dimension for each 1 ft of such height. The depth of a rear yard at its lowest level shall be at least 15% of the depth of the lot, but need not exceed 15 ft at such level. If a building in an E district is located in a residence district as designated on the use district map, the depth of a rear yard at its lowest level shall be at least 25% of the depth of the lot, but need not exceed 25 ft at such level. However, for each 1 ft in excess of 10 ft of the depth of such rear yard at its lowest level there may be substituted 1 ft of depth of unoccupied space across the whole width of the front of the lot at the curb level between the street line and the street wall of the building. In an E district on at least one side of every building located within a residence district there shall be a side yard along the side lot line for the full depth of the lot or back to the rear yard.

2. In an E district an outer court or side yard at any given height shall be at least 2½ in in least dimension for each 1 ft of such height. On a lot not more than 50 ft in mean width an outer court or a side yard at any given height shall be at least 2 in in least dimension for each 1 ft of such height. An outer court at any given point shall be at least 2½ in in least dimension for each 1 ft of length.

3. In an E district no building located within a residence district as designated on the use district map shall occupy at the curb level more than 50% of the area of the lot if an interior lot, or 70% if a corner lot, and above a level 18 ft above the curb no building shall occupy more than 30% of the area of the lot if an interior lot, or 40% if a corner lot. In computing such percentage, any part of the area of any corner lot in excess of 8000 sq ft shall be considered an interior lot.

"Rear Yards. 1. Except in A districts, for lots or portions of lots that are back to back there shall be rear yards extending along the rear lot lines of such lots or portions of lots wherever they are more than 55 ft back from the nearest street. Such rear yard shall be at least of the area and dimensions herein prescribed for the area district in which it is located at every point along such rear lot line. Within 55 ft of the nearest street no rear yards shall be required. No rear yard shall be required on any corner lot nor on the portion of any lot that is back to back with a corner lot.

2. Where a building is not within a residence district as designated on the use district map, the lowest level of a rear yard shall not be above the sill level of the second story windows, nor in any case more than 23 ft above the curb level. Where a building is within a residence district the lowest level of a rear yard shall not be above the curb level, except that not more than 40% of the area of the yard may be occupied by the building up to a level 18 ft above the curb level. In the case of a church, whether within or without a residence district, such 40% may be occupied up to a level of 30 ft above the curb level.

3. Chimneys or flues may be erected within a rear yard provided they do not exceed 5 sq ft in area in the aggregate and do not obstruct ventilation.

4. Except in A districts, where a building on an interior lot between lots for which rear yards are required runs thru the block from street to street or to within 55 ft of another street, there shall be on each side lot line above the sill level of the second-story windows and in any case above a level 23 ft above the curb level a court of at least equivalent area at any given height to that required for an inner court at such height and having a least dimension not less than that required for an outer court at the same height.

5. When a proposed building is on a lot which is back to back with a lot or lots on which there is a building or buildings having rear yards less in depth than would

be required under this article, the depth of the rear yard of the proposed building shall not be required to be greater at any given level than the average depth of the rear yards directly back to back with it at such level, but in no case shall the depth of such rear yard be less at any height than the least dimension prescribed for an outer court at such height.

"Courts. 1. If a room in which persons live, sleep, work or congregate receives its light and air in whole or in part directly from an open space on the same lot with the building, there shall be at least one inner court, outer court, side yard or rear yard upon which a window or ventilating skylight opens from such room. Such inner court, outer court or side yard shall be at least of the area and dimensions herein prescribed for the area district in which it is located. Such rear yard shall be at least of the area and dimensions herein prescribed for an inner court in the area district in which it is located. In an A district, such inner court, outer court, side yard or rear yard shall be at least of the area and dimensions herein prescribed for a court in such district. The unoccupied space within the lot in front of every part of such window shall be not less than 3 ft, measured at right angles thereto. Courts, yards and other open spaces, if provided in addition to those required by this section, need not be of the area and dimensions herein prescribed. The provisions of this section shall not be deemed to apply to courts or shafts for bathrooms, toilet compartments, hallways or stairways.

2. The least dimension of an outer court, inner court or side yard at its lowest level shall be not less than 4 ft, except that where the walls bounding a side yard within the lot are not more than 25 ft in mean height and not more than 40 ft in length, such least dimension, except in an E district, may be not less than 3 ft. Where any outer court opens on a street, such street may be considered as part of such court.

3. The least dimension of an inner court at any given height shall be not less than that which would be required in inches for each 1 ft of height for a rear yard of the same height, except that an inner court of equivalent area may be substituted for said court, provided that for such area its least dimension be not less than one-half of its greatest dimension. If an inner court is connected with a street by a side yard, for each 1 ft that such side yard is less than 65 ft in depth from the street 1 sq ft may be deducted from the required area of the inner court for each 15 ft of height of such court. If the lot is not required under this resolution to have a rear yard, an outer court, not opening on a street, shall open at any level on an inner court on the rear line of the lot and such inner court shall be deemed a rear yard in such case.

"Area District Exceptions. 1. The area required in a court or yard at any given level shall be open from such level to the sky unobstructed, except for the ordinary projections of skylights and parapets above the bottom of such court or yard, and except for the ordinary projections of window sills, belt courses, cornices and other ornamental features to the extent of not more than 4 in. However, where a side yard or an outer court opens on a street a cornice may project not over 5 ft into such side yard or outer court within 5 ft of the street wall of the building.

2. An open or lattice-enclosed iron fire escape, fireproof outside stairway or solid-floored balcony to a fire tower may project not more than 4 ft into a rear yard or an inner court, except that an open or lattice-enclosed iron fire escape may project not more than 8 ft into a rear yard or into an inner court when it does not occupy more than 20% of the area of such inner court.

3. A corner of a court or yard may be cut off between walls of the same building provided that the length of the wall of such cut-off does not exceed 7 ft.

4. An offset to a court or yard may be considered as a part of such court or yard provided that it is no deeper in any part than it is wide on the open side and that such open side be in no case less than 6 ft wide.

5. If a building is erected on the same lot with another building, the several buildings shall, for the purposes of this article, be considered as a single building. Any structure, whether independent of or attached to a building, shall for the purposes of this article be deemed a building or a part of a building.

6. If an additional story or stories are added to a building existing at the time of the passage of this resolution, the courts and yards of which do not conform to the requirements of this article, the least dimensions of yards and courts shall be increased from the top of the existing yard or court walls as tho they were of the prescribed

dimensions at such heights, and the carrying up of existing elevator and stair enclosures shall be exempted from the provisions of this article."

The regulations described in Arts. 25, 26 and 27 have been outlined in some detail in order that engineers who are responsible for the planning of streets and street systems may appreciate the tendencies in this direction. If municipal authorities are to impose restrictions of the kind described, the streets can often be planned in quite a different manner than would be the case if the owners of private property are to be allowed to continue the development of their holdings in any manner which may seem most advantageous to themselves.

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SECTION 8

GRADING, DRAINAGE AND FOUNDATIONS

BY

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GRADING

1. Clearing and Grubbing

Before the construction of embankments and excavations are begun, trees, stumps, large roots, brush and other objectionable material within the entire area to be covered by the fill should be removed. Where the fill is less than about 2 ft in depth, all vegetable matter should be removed from the original surface. These requirements are necessary in order to secure embankments free from soft and spongy pockets.

Specifications. Also contained in general grading specifications (see Art. 5).

Penn. Highway Dept. "The ground shall be cleared of all trees, stumps, brush, roots, fences, walls, buildings, or other incumbrances upon or within the limits of the roadway before grading is commenced. The Contractor shall burn, or otherwise dispose of all such trees, stumps, roots, etc, in a satisfactory manner and shall remove all rubbish or refuse to such point, or points, beyond the limits of the work, as may be

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directed. When it is necessary to remove a fence, or fences, for the prosecution of the work, the Contractor shall do such work with proper care and shall place the materials so removed on the abutting property in a satisfactory manner."

Am. Ry. Eng. Assn. (13). "EXTENT OF CLEARING. The right-of-way and station grounds, except any portions thereof that may be reserved, shall be cleared of all trees, brush and perishable materials of whatsoever nature.

"DISPOSAL OF BRUSH, ETC. All these materials, except as hereinafter mentioned, shall be burned or otherwise removed, as may be directed, and without injury to adjoining property.

"STUMPS. Where clearing is to be done, stumps shall be cut close to the ground, not higher than the stump-top diameter for trees 12 in and less in diameter, and not higher than 18 in for trees whose stump-top diameter exceeds 12 in, except between slope stakes of embankments, where stumps shall be cut so that the depth of filling over them shall be not less than 2½ ft.

"CLEARING IN ADVANCE. The work of clearing shall be kept at least 1000 ft in advance of grading.

"CUTTING AND PILING WOOD. All trees which may be reserved shall be stripped of their tops and branches, made into ties, or cut to such lengths as may be directed, and neatly piled at such places on the right-of-way as may be designated, for which service payment shall be made by the tie, or by the cord of 128 cu ft.

"ISOLATED TREES, BUILDINGS, ETC. Where isolated trees, or where buildings exist, payment shall be made for the removal thereof at a price to be agreed upon before removal.

"MEASUREMENT OF CLEARING and payment for the same shall be by units of 100 ft square, or fraction thereof, actually cleared.

"EXTENT OF GRUBBING. Stumps shall be grubbed entirely from all places where excavations occur, including ground from which material is to be borrowed as well as from ditches, new channels for waterways and other places where required. Grubbing shall also be required between the slope stakes of all embankments of less than 2½ ft in height.

"GRUBBING IN ADVANCE. The work of grubbing shall be kept at least 300 ft in advance of grading.

"MEASUREMENT OF GRUBBING shall be estimated upon all excavation actually done, and the space to be covered by all embankments of less than 2½ ft in height. Payment for the same shall be by units of 100 ft square, or fraction thereof, actually grubbed."

Methods and Cost Data. CLEARING AND GRUBBING (40b). "The area covered was nine acres, the trees being rather closely spaced, and the undergrowth, without being rank, was of long standing. The trees ranged in size from 6 in to 3 ft in diameter, the average being about 20 in. Everything smaller than this was classed as brush and the stumps were grubbed with a mattock. The stumps of trees were blasted. The number of trees cut was over 1100, while the actual number of stumps blasted was 1212. The trees were first cut down, and the brush and leaf wood piled and burnt. Then the blasting commenced, while choppers sawed and split up the trees into cord wood and saw logs. The timber consisted of oak, hickory, chestnut, and a scattering of a few other varieties. The work was done in the spring of the year, the weather being good.

"The tools used for cutting and grubbing were as follows: 33 axes, 29 mattocks, 30 shovels, 1 hatchet, 1 handsaw, one 4-ft cross-cut saw, two 6-ft cross-cut saws, 2 files, 2 water buckets, and 2 grindstones. For blasting the following were used: 1 churn drill, 1 large auger and 1 bucket. These tools cost about $80, which could be charged at a rate of $9 per acre to the job. Foremen were paid $2.50 per 10-hr day and laborers, mostly Italians, were paid $1.25. The details of the total cost of the entire job were as follows:

	Total	Per Acre
Chopping	$169.61	$18.84
Grubbing and clearing	139.74	15.53
Making cord wood	91.25	10.14
Blasting	663.59	73.73
Grubbing after blasting	317.36	35.26
Grinding axes	5.87	.65
Tools	81.00	9.00
Total	$1468.42	$163.25

Blasting Stumps (31h). "The number, size and condition of stumps and the kind of soil in which they rest have an important bearing on the cost of land clearing. It takes perhaps twice as much dynamite to blast a stump out of dry, sandy soil than it does out of moist and dense ground. The removal of a green stump also requires the use of much more dynamite than is necessary for the blasting of an old stump.

"Ruzek reports that he removed 482 stumps from a farm near Watertown, Wis., at a total cost of a little less than $100. The stumps ranged in size from 6 in to 3 ft and the timber had been cut for about 9 years. It required from ¼ to 6½ lb of 40% dynamite to the stump.

"Campbell gives some comparative figures on blasting in sandy and clay soils. On one farm there were 28 pine stumps in light, sandy soil. The cost was $38.77. As high as 18 lb of dynamite were used under one stump, 12 lb under another and from 1½ to 10 lb under the rest. On another farm, where a dry soil predominates, 81 stumps were taken out. The work cost $14.11. The stumps were elm, oak, maple, ash, and basswood. These stumps were of about the same average size as the stumps on the first farm, yet it was possible to get out 81 of them for a little more than a third what it cost to blast 28 out of sandy soil.

"Bradley reports that he blasted 126 red and burr oak stumps, ranging from 30 to 75 in in diameter out of some black sandy soil. The timber had been cut 5 years. The only tool required was a 1½-in wood auger. With this tool he bored holes in the ground, being careful to get the end of the hole down 4 to 8 in past the center of the stump. He considers it very important to have at least 20 in of soil between the charge and the stump itself. If the charges are loaded too close up under the stumps they are apt merely to split the stump and blow the sand out from around the base. The roots remain firmly imbedded in the ground. In this condition they are practically impossible to blast out and must be dug and chopped out. For these 126 stumps, he used 486 lb of 40% dynamite, 189 caps and 378 ft of fuse. The entire cost of the work, including labor, was $112.79."

Pulling Stumps. Shattuck states that (56) "The donkey engine, the caterpillar, or the ordinary traction engine used in threshing may each be operated to advantage on stumps of various sizes, depending on the power of the engine used. The 60-hp donkey engine will pull practically any sound stump up to 30 in in diameter and almost any cracked stump. It will also clear from 3 to 5 acres at one setting and pile the same. An efficient crew can pull, pile, and burn the stumps remaining where heavy cedar, fir, white pine, and tamarack timber has been removed at from $75 to $115 per acre, the cost being distributed as follows: Preliminary work, $25 to $40.00; pulling, $30 to $50.00; burning, $10 to $12.50; leveling, $10 to $12.50; total, $75 to $115.00. The trees probably averaged 80 to the acre and 30 in in diameter, and were mostly sound. The cost of burning and leveling is considerably increased by failure to remove all the earth possible from the stumps before piling and also by making the piles too large.

"The Holt caterpillar 60-hp engine will remove sound stumps up to 18 or 20 in and the caterpillar feature gives it a very decided advantage in getting over uneven or swampy ground. It also works rapidly and is very efficient for small stumps and young standing timber. It has been known to pull 100 stumps per hour for 7½ hr on a speed test, and has also averaged 450 stumps per day at regular land-clearing work.

"The ordinary traction engine used in threshing, wood-sawing, etc, can be so rigged as to pull small stumps and young trees much as described for the caterpillar. This machine works well on sound stumps under 12 in and on well-cracked stumps or on small timber. These machines are not so easily handled on rough or swamp ground, nor are they as fast as the caterpillar engine."

2. Excavation and Embankment

Classification of Materials. Different kinds of soils are described under the terms gravel, sand, clay, marl, loam, peat, and muck. See Sect. 3. It is quite common in grading specifications to classify the materials to be excavated as earth, hardpan, loose rock, and solid rock: earth to include clay, sand, loam, gravel, and all hard material that can be reasonably plowed, and all earthy matter or earth containing loose stones or boulders intermixed, and all other material that does not come under the classification of hard-

pan, loose or solid rock; hardpan to include all material, not loose or solid rock, that cannot be reasonably plowed on account of its own inherent hardness; loose rock to include all stone and detached rock, found in separate masses, containing not less than 1 cu ft, nor more than ½ cu yd, and all slate or other rock soft or loose enough to be removed without blasting, altho blasting may occasionally be used; solid rock to include all rock in place and boulders measuring ½ cu yd and over, in removing which it is necessary to resort to drilling and blasting. See Art. 5.

Portland, Oregon, Specifications Covering Classification of Materials. "Materials encountered in excavation will be classified as follows:

"EARTH will include clay, sand, gravel, loam and all other materials of an earthy nature, however excavated, and decomposed rock, slate, boulders, etc, having a volume of less than ½ cu ft;

"LOOSE ROCK will include all boulders and detached masses of rock having a volume of not less than ½ cu ft and not more than ½ cu yd, and such other material as may not be loosened, plowed or broken by means of a heavy 10-in rooting-plow, drawn by 6 heavy horses, such as is commonly used in breaking heavy ground;

"SOLID ROCK will include all rock found in ledges and in masses of over ½ cu yd.

"Note: Old macadam roadway shall not be considered as included in any of the above classifications and excavation of such material shall be paid for under the unit price quoted in the bid for the particular thickness of roadway."

Excavation. In excavating material in order that the cross-section of a highway should conform to the desired lines and grades, the operations vary from the removal of a small amount of material in surface grading to excavations of many feet in depth. Excavation generally includes excavation of the roadway, ditches and side slopes. Usually excavated material is used in the construction of fills. Surplus excavation is used in many cases to widen embankments and to flatten side slopes, but in some cases is wasted by being deposited in spoil banks. Methods of excavation with various machines are explained in Art. 4 in connection with the descriptions of grading machines.

LOOSENING SOIL WITH EXPLOSIVES (52a). "For removing stumps and boulders its value is generally recognized but it has been found economical in many cases to use it in excavating drainage ditches along the sides of roads and in assisting grading down to the road level.

"Where a ditch is to be dug in hard soil, this may be loosened and to a considerable extent blown out by punching a number of shallow holes along the line of the ditch and charging these with small amounts of dynamite. The holes should be deeper than the bottom of the ditch and can be spaced two or three feet apart. Where the ditch is in saturated soil, it is recommended that the holes be placed about 18 to 24 in apart and 50% dynamite be placed at a depth a little less than that of the ditch. One hundred or more of these charges may be fired with a single cap. If the ground is dry or cold, the holes are punched further apart and loaded with low-freezing explosive, each charge being primed with an electric blasting cap so that all may be fired at one time. For small ditches, quarry powder or other with similar characteristics will give good results. A single row of holes can be used to blast out a ditch from 1½ to 4½ ft deep and from 4 to 7 ft wide in dry soils and 5 to 9 ft wide in wet soils. If wider ditches are required, two rows of holes 3 or 4 ft apart, fired at the same time, can be used.

"Still another method of using explosives is in making deep cuts, as in grading or widening a road. In this case the excavation is given a comparatively vertical face or bench and a line of holes is drilled or punched down from the top parallel to the face and spaced back a distance about one-quarter greater than the depth of the cut and about the same distance apart. The holes are loaded with low strength dynamite, 20 or 30%, the amount used in each hole depending on the hardness of the ground and depth of hole. If the cut is deeper than 6 ft, the holes are seldom placed more than that distance from the face. The holes should not be carried below grade as this may loosen the subgrade too much. With low-grade explosive the hole may be filled about

one-half full of dynamite and carefully tamped to the collar. A number of holes should be fired at once with electric caps, as better results are obtained in this way."

REMOVAL OF LIGHT EXCAVATION (27d). "When it is desired to load the loosened material into wagons, the material can first be scraped into piles by several methods. If the excavation is more than 6 or 8 in deep and hand loading must be done, it is not necessary to scrape the earth into piles, as a shovel can be filled in the well loosened material. For lighter depths, however, a man cannot get a shovelful, so it is necessary first to pile the material in long windrows. The ordinary drag or the Fresno scraper can be used for this purpose. With these scrapers the pile can be a long one or a number of small piles can be made. When horses are used for plowing, the same animals can be used to make the piles. The road graders can also be used to place the loosened dirt into a row, but the machine may have to go over the same area several times in order to get it up clean. A better machine than these for this purpose is a trench back filler. These machines consist of a hoisting device and a scraper that pulls the dirt towards the machine, dumping it into the open trench. For piling, it can be used in the same manner, by first going down one side of the road drawing all the earth on the other side into a pile at the center. Then the machine travels on the side it has cleaned up, drawing the material on the first side into the same pile in the center. Thus the earth is all piled mechanically.

ROCK EXCAVATION (27e). "If there is a large amount of rock in one cut or in different cuts on the job, then hammer drills should be installed upon the work. These drills can be operated by steam, electricity or air. A small portable boiler can be used for steam, or a small portable air compressor operated by gasoline can supply the air. Either of these can be operated economically. These plug or hammer drills will drill holes a few inches deep as well as a few feet. In fact, they are ideal for holes 5 to 8 ft deep and the latest types will drill holes up to a depth of 12 ft. Thus a set of these drills will answer for much rock work. Time is saved by them in the ease with which men can handle them, changing from one hole to another, while the ordinary air drill must be taken down, the tripod moved and the drill set up and trued for the hole. One man will operate a plug drill while two men must be used on the ordinary steam or air drills. Then, too, time is saved in mucking out the holes unless a jet of water is used for the larger drills.

"However, if the rock cuts are large and 8 or more feet deep, the regular drills should be used, a few plug drills being employed to break up boulders and for drilling the bottom or edges of the cut. On heavy work the larger drills will do more economical work. If very heavy rock cuts must be excavated, instead of taking them out in two lifts as will be necessary with the ordinary drills, well drillers should be used for driving the holes. For very deep drilling, these will be found more economical, but to use them does not mean that some of the other two types of drills should not be kept on the job. A common mistake is to get rid of all the other drills as soon as a well driller is installed. Even where most of the drilling is for deep holes, there are bound to be some shallow holes to drill, and the heavier the rock blasting the more large boulders there will be. For this work the lighter drill must be used, not that the larger type of drill cannot be used, but it is too expensive to move it and set it up.

"For all the rock blasting except the very light cuts and for shale or rotten sandstone, the rock should be worked from a breast in order to attain the most economical results. Not only is the drilling less expensive, due to the fact that less drilling must be done, but the work of the explosive is more effective. As a rule, too, the mucking can be done cheaper. In very light rock work the mucking must be done by hand, except where such machines as steam shovels are installed for the rest of the excavation. For heavier work, besides steam shovels, several types of loaders and excavators can be used. Derricks with skips or grab buckets, and scrapers of several different types will also handle excavated rock. Hand methods for this work should not be used if it will pay to install machinery. Inasmuch as almost any machine that will handle rock will likewise handle earth, it is possible to make machinery pay on street and road excavation.

"For heavy rock blasting, dynamite should be used to break boulders and for other shallow hole blasting, but for the heavier work it is seldom economical. For all heavy blasting, block powder or, better still, some form of granular powder containing a small percent of nitroglycerine, should be used. The nearness of improved property to rock excavation means that heavy blasts cannot always be made. Under such cir-

cumstances, the rock may have to be taken out in lifts, and it will be necessary to cover each blast with mats, logs and rock. However, it is quite surprising how heavy blasts can be made without doing damage to surrounding property if the proper care is taken and each charge is carefully figured to break up the rock without heaving it. It is for such rock that the granular powders are especially suited, as the blast may be well confined, causing it to break up and pulverize the rock without throwing it out and injuring things. If the proper charge is used there will be but a slight concussion, as the energy of the explosive will be used upon the rock. The jarring of the earth by a blast cannot be prevented."

Blasting Boulders. Knight (46) states that: "There are three distinct methods successfully employed to-day in the blasting of boulders from building sites or railroad and highway right-of-ways. These are blockholing, snakeholing, and mud-capping. A shot combining both snakeholing and mud-capping is sometimes made on very large boulders where it is not practical to drill into the rock for a blockhole shot. Of these methods employed, blockholding requires the least amount of dynamite, but calls for the greatest amount of labor. Mud-capping demands the greatest amount of dynamite and the least amount of labor and time, while snakeholing lies between the two, as it requires a moderate amount of both dynamite and labor.

BLOCKHOLE METHOD. "Probably the best way to break up very hard boulders is by the blockhole method. This consists in boring a hole about 1¼ in in diameter about half way thru the boulder. The dynamite used should be removed from the cartridge and packed firmly into the bottom of the hole.

Approximate Amount of Dynamite Required to Break Boulders, Based on Using a 50% Strength Straight Nitroglycerine Dynamite

Diam. of Boulder in Feet	Number of Cartridges Required		
	Mud-capping	Snakeholing	Blockholing
1½	2	1	¼
2	3	1	¼
3	4	1½	½
4	Not practicable	4	¾
5	Not practicable	6	1

"A small hole is made in this firmly pressed dynamite with a sharp stick, and in this is inserted a blasting cap and fuse. The hole is then tamped full of moist earth. Care should be taken to have this tamping material packed very firmly. The gases caused by the explosion are so perfectly confined by this method that excellent results may be secured with a comparatively small amount of a low strength dynamite. A glance at the accompanying table shows that it requires only about one-eighth as much dynamite to break a boulder this way as it would to break it by mud-capping.

SNAKEHOLE METHOD. "In breaking a boulder by the snakehole process, a hole is punched down with a bar directly under but alongside of the boulder. The hole should be punched deep enough so that the charge of dynamite will rest directly under the heaviest part of the boulder. The dynamite cartridges are placed in the bore hole in as compact a position as possible, and to secure this the cartridges are generally slit. A primer is inserted and the bore hole packed tightly with a moist, plastic material. Blasts of this sort are generally fired with blasting cap and fuse. A 40% Extra dynamite is best suited for work of this sort. Electric blasting is not generally resorted to unless the boulder is very large and two or more shots are required.

"MUD-CAPPING is the easiest method of all. While it requires the most dynamite of any, yet it is not necessarily the costliest, as the saving of time and labor goes a long way toward paying for the extra dynamite that is required. In mud-capping, the dynamite is taken from the cartridge and is placed on the boulder in a conical shaped pile just where the boulder would be hit with a sledge, if it were possible to break it in this manner. The explosive is packed down firmly and a blasting cap and fuse are put in the top of this miniature pyramid. A covering of thick, plastic mud must be placed over this dynamite. This should be at least 5 or 6 in in thickness. Care should be observed to see that this mud covering is free from stones or other heavy matter, as the force of the explosion will throw such material at terrific speed. A stone or plank should never be placed on top of the mud-cap for the same reason. A quick-

acting dynamite is required for this class of work, and the Extras or a Straight Nitro-glycerine dynamite will produce the best results. A 40% Extra will be found satisfactory on easily broken rock, but on very hard rock a 50% Straight dynamite will be required. If a portion of the boulder extends into the ground, do not try to break it by mud-capping, as the confining dirt makes it harder for the explosives to do their work. In cases of this sort the boulder may be rolled out by a snakehole shot and then broken by mud-capping.

"FIRING CHARGES. When blasting boulders near a highway or railroad where there is more or less travel, it will probably be better to fire the charges electrically. This has the advantage over the blasting cap and fuse insomuch that the exact instant of explosion is under the control of the operator of the blasting machine, and the charge may be fired at the moment desired."

Cost Data on Breaking and Removal of Boulders (40a). "In breaking up boulders the following six methods can be used: (1) Boulders can be broken with plug and feathers; (2) by heating and pouring water on them; (3) by sledging ; (4) by mud-capping; (5) by blocking; and (6) by placing a charge of explosives under the boulders. Each of these methods has its uses and misuses.

"PLUG AND FEATHERS. Drilling the rock with a hand-drill and then splitting with plugs and feathers is in common use, when the stone is to be used for building purposes as for culverts and bridges. The cost of this work varies according to the hardness of the rock, the size to which the stone is to be broken and the price paid for such work. The following are the costs of some examples of this class of work, hand-drillers being paid $1.50 for 10 hr work: 1¼ cu yd were taken off the slope of a sandstone cut at a cost of $1.50; 3 cu yd were taken off the slope of a sandstone cut at a cost of $2.25.

"SLEDGING. Under a competent and watchful foreman many large size boulders can be broken up with a stone sledge and gad, saving the use of explosives. By looking closely for seams and cracks and taking advantage of these, and at other times using the pean end of the hammer with the rift of the rock, many boulders containing 1 cu yd or less can be quickly broken. The following are some records of costs of breaking up boulders by sledging. These figures do not include moving the pieces after the boulder is broken, but all the pieces could be easily handled. Wages paid were $1.50 for a working day of 10 hr. (1) Hard blue sandstone, 7½ cu ft, 1 man, 3 min, makes a cost of 0.75 cents, or 2.7 cents per cu yd. (2) Blue sandstone, 12½ cu ft, 1 man, 5 min, 2 men, 2 min, makes a cost of 2.25 cents, or 4.86 cents per cu yd. (3) Blue sandstone, 16 cu ft, 1 man, 3 min, makes a cost of 0.75 cents, or 1.25 cents per cu yd. (4) Red sandstone, 1 cu yd, 3 men, 10 min, makes a cost of 7.5 cents per cu yd.

"MUD-CAPPING. This work can, as a rule, be done so quickly that the method has come into universal favor among foremen but the great objection to it is the almost prohibitory cost. On account of this great loss mud-capping should be condemned, as upon most occasions cheaper methods can be used. The only reason that should ever commend it to the thoughtful contractor, is the saving of time in preparing the shot. For this reason, in thru cuts, mud-capping may occasionally be resorted to, but in side hill cuts and borrow pits, where the work of sledging and drilling will not interfere with the labor of the muckers, this method should under no circumstances be used. The following are records of costs. Labor was paid $1.50 per day of 10 hr, 40% dynamite cost 10 cents per lb, caps 60 cents per 100 and fuse 42 cents per 100 ft. Red sandstone, 1.6 cu yd, labor 8 cents, dynamite 20 cents, cap and fuse 2 cents; total cost 30 cents or nearly 18 cents per cu yd. Red sandstone, 1 cu yd, labor 8 cents, dynamite 15 cents, cap and fuse 2 cents; total 25 cents. Blue sandstone, 1.2 cu yd, labor 8 cents, dynamite 20 cents, cap and fuse 2 cents; total cost 30 cents or 25 cents per cu yd; this broke the boulder, but a part of it had to be sledged at a cost of 5 cents. Blue sandstone, ½ cu yd, labor 10 cents, dynamite 7½ cents, cap and fuse 2 cents; total 19½ cents or 39 cents per cu yd.

"PLACING CHARGE UNDER BOULDER. The method of placing the charge of dynamite under the boulder in order to break it has not been used extensively, and for this reason it is difficult to obtain costs of this method. That it can and should be used on account of its cheapness over other methods, should commend it to contractors. The charge can easily be placed under the rock by either raising the boulder up with bars or levers, or churning a hole under it with a drill. In some cases the boulder

can be turned over and the charge placed as this is being done. At least 50 to 60% of the charge necessary to mud cap a boulder can be saved by this method, and the work can be done as quickly. The rock, as a rule, will not only be broken up, but most of it will be thrown out of the cut. For this reason, where there can be no waste of material, engineers may prohibit this method. A red sandstone boulder, 9 cu yd, was completely blown away at the following cost: Labor 10 cents, dynamite 5½ cents, cap and fuse 2 cents; total cost 17½ cents; cost per cu yd, 19.4 cents. Labor in this case was $1.35 per day and dynamite cost 11 cents per lb. A large boulder sticking into the base of the slope of a cut had 1½ cu yd shot off of it by putting the charge under the projecting end. Labor 13 cents, dynamite 16½ cents, cap and fuse 2 cents; total cost 31½ cents; cost per cu yd 21 cents. About ½ cu yd was thrown out of the cut and the rest was broken up, so it could be handled. Labor and dynamite cost the same as in the first case.

Embankments. If stone fill is employed, usually the stone should not exceed ½ cu ft in size and the large stones should be placed in the bottom of the excavation. No large stone should be used within 6 in of the surface of the subgrade or shoulders. In the construction of embankment. it is of the utmost importance that the material should be thoroly compacted in order to avoid later settlement. In order to accomplish this result, the material to form the embankments should be deposited in thin layers, not over 12 in in depth, for the full width of the embankments and thoroly compacted. The compaction is accomplished by machines and loaded wagons used in grading operations, being drawn continually over the embankment, and by rolling. In some cases, the best results have been obtained by the use of sectional rollers or comparatively light rollers on thin layers of materials. Methods of constructing embankments with various machines are explained in Art. 4 in connection with the descriptions of grading machines.

Use of Water in Embankment Construction (27b). "Water is a great aid in settling new embankments, so that any bank built by a hydraulic process will show little settlement. Thus a bank sluiced into place with a hydraulic giant is an excellent one for a road. Likewise, those placed by hydraulic suction dredges can be recommended and even the embankments for roads built near or on the banks of streams from the materials from their beds, by cableway excavations, as in Indianapolis, Ind., and other sections of the Middle West, show but little settlement. In other places, such embankments are built by drag line scrapers, grab buckets, or dipper dredges from the bed of streams, either dumping directly into the embankments or loading the material into cars or skips for placing in the bank.

"Even with other excavating machines, it is sometimes possible to use water to puddle the embankment. This can be done by two methods. One is by using water from a hose or pipe to wet the material at certain intervals, not simply sprinkling, but so saturating it with water as to drench it, using water up to the limit, yet not washing the material away. It is not always possible to use this method and yet continue hauling onto the embankment, unless the work is so planned as to wet the embankments in sections and yet retain some sections for hauling and dumping. The second method is to build the sides of an embankment up for short heights first, and to build small embankments of the same height across the bank, dividing it into sections. This will give a number of shallow ponds which can be filled with water. Then, while the water is maintained by these dams, earth can be dumped into the ponds until they are filled. This completely puddles the embankment. However, these methods cannot be used when the water will injure adjacent property or where it is not possible to obtain the supply of water economically."

Shrinkage of Materials. It is important in grading operations to distinguish between loose measurement and measurement in place. Estimates are usually based on the yardage of material in place. It is a well established fact that earth, when removed from its original position in a bank, increases in bulk or swells. It is also well known that when the excavated material is placed in a fill it will shrink and settle so that

it will usually occupy a smaller space than it did originally. The swelling on removal from the original bank will vary generally from about 8 to 15%, but in some cases may be as high as 40 to 50%. The shrinkage is variable and depends upon the kind of earth, the manner in which the embankment is made, and the climatic conditions.

Loss of Material by Removal of Stumps (38). "The following data will apply on the Pacific coast for computing loss of excavation by blowing out stumps. Fir, cedar, spruce, hemlock are averaged: 6 to 12 in, 1 cu yd each; 12 to 24 in, 3 cu yd each; 24 to 36 in, 5 cu yd each; above 36 in, 10 cu yd each. In swamps where the growth is spruce, hemlock, cedar, maple, 50% should be added to these quantities, as it requires more dynamite to lift a stump of given size, owing to the decreased resistance of the swamp soils."

Overhaul. When the excavating material suitable for use in the construction of embankments is insufficient, additional material is obtained from borrow pits or other sources. In cases where the haul of material required for embankments exceeds a given distance, the work entailed is classified as overhaul. If this distance is 500 ft, payment for overhaul would be based upon a rate per cubic yard for each 100 lin ft greater than 500 ft which the material is hauled. For specifications covering overhaul, see Art. 5.

Grading on Side Hills. In the construction of highways on side hills, it is advisable to stagger or roughen the material of the hillside in order to form a mechanical bond between the material of the fill and the surface of the ground, thus guarding against the slipping of the embankment. See Sect. 3.

Penn. Highway Dept. Specifications for Hillside Embankments. "When embankments are to be made on a hillside the slope of the original ground under the fill shall be ploughed deeply or cut into steps before the filling or embankment is commenced. All such embankments so made shall be rolled thoroly, as stated above, or where the bottom of the fill is of insufficient width to permit the use of a roller, the material shall be tamped thoroly and satisfactorily."

Viaduct on Hillside (32b). "The highway at these places is located on a steep mountainside. To excavate a 24-ft roadway out of the hillside would have meant the moving of an enormous quantity of earth with no place to dump it. In order to avoid this, viaducts were erected. Essentially the construction is a solid reinforced concrete slab, crowned to the road crown, which rests on transverse floor-beams spanning between columns on the low side and a continuous girder on the high side. These columns are spaced every 20 ft and foot on prismatic bases. The up-hill girder rests on square concrete plates and the plates and column footings are tied together by reinforced concrete struts taking the slope and embedded in the ground. Longitudinal stiffness is also given by girders at the top of the columns under the railing."

Side Slopes. When the excavations and embankments are on roads, one of the most important details of grading operations is the formation of the side slopes in such a manner that the cross-section of the highway will retain its form. In many cases, in order to avoid washing away of side slopes during heavy rains, the slopes of both excavations and embankments are sowed with grass seed or covered with sod. The slopes of banks are commonly expressed in terms of the horizontal distance for each vertical foot of rise, thus $1^1/_2 : 1$ would mean that the line of the slope makes an angle with the horizontal whose tangent was $1/1^1/_2$. The slopes vary depending upon the material of which the bank is composed and should be made equal to the angle of repose of the material in order to keep the same from sliding. Following are given some of the slopes in cuts adopted in practice for different materials: earth $1^1/_2 : 1$, sand $2 : 1$, rock $^1/_4 : 1$ or $^1/_6 : 1$. On embankments the bank slopes are generally made $1^1/_2 : 1$ for fills over 4 ft in depth. For fills under 4 ft, the slopes are

sometimes made 4 : 1 in order to eliminate danger to traffic. This practice is generally more economical than building a guard rail on a 4-ft fill with a $1\frac{1}{2}$: 1 slope. The width of shoulders is increased from 1 to 2 ft on embankments where a $1\frac{1}{2}$: 1 slope is used, and is made the same as in cuts where a 4 : 1 slope is used.

Grasses for Slopes. Buetow (25) states that: "When selecting grasses to be planted on the slopes, it should be kept in mind that a grass with a good system of roots is to be used, as well as one able to withstand the hot rays of the sun. Grasses that will grow on a sunny bank probably will not take root and form a mat on the shaded slopes, in which case a different kind of grass is necessary. The protection to the bank lies almost wholly in the ability of the roots to interweave so minutely as to form a system to reinforce the surface stratum. Hungarian brome-grass, Canadian blue-grass, fescue-grasses and Western wheat-grass are good to plant. In many cases sod is handy to get and, when properly cut and placed, offers very good protection. The sods must be held in place by wooden pegs until the grass has taken root.

"Seeding and planting are equally successful when conducted properly. The surface in each case must be prepared in order to make it at all conducive to a good growth. The seed cannot be merely distributed on the slope and left with the hope that it will catch. If necessary, the ground should be manured before any seeding is done and if a sandy slope is treated, the surface must be protected from the wind with straw or brush until the grasses are able to withstand the elements.

"Different kinds of soil require a certain kind of grass or a combination of several kinds. For shaded places a combination of Kentucky blue-grass, wood meadow-grass, crested dog's tail and various leaved fescues are well adapted. Clay soils can be treated with a mixture of Kentucky blue-grass, English rye and fancy redtop. The rye grass gives an early quick result, the redtop makes a bottom grass, and the blue-grass is the permanent feature. Sandy soils require a quickly growing binding grass that will withstand the drought. Creeping bent, Rhode Island bent and fine-leaved fescue are grasses that answer this purpose. Western wheat-grass has unusual ability to grow on the sunny side of an embankment. Creeping bent, Canada and Kentucky blue-grass and crested dog's tail are quick-growing, deep-rooting grasses that will bind the soil until such time as the more permanent grasses are in possession. Sweet clover and creeping honeysuckle are recommended for planting in cuts."

Am. Ry. Eng. Assn. Specifications Covering Construction of Slopes (13). "The slopes of embankments and excavations shall be of the following inclinations, as expressed in the ratio of the horizontal distance to the vertical rise. Embankments, earth, $1\frac{1}{2}$ to 1; rock from 1 to 1, to $1\frac{1}{2}$ to 1. Excavations, earth, $1\frac{1}{2}$ to 1; loose rock, $\frac{1}{2}$ to 1; solid rock, $\frac{1}{4}$ to 1. These ratios may be varied according to circumstances, and the slopes shall be made as directed in each particular case."

Sodding Slopes with Bermuda Grass. "The slopes shall be graded to a uniform surface and all depressions filled in with suitable material and padded down firmly with a shovel.

"If the material of the slope is not fertile it shall be given a dressing of 6 in of good rich loam. If good loam is not available, a dressing of manure shall be placed on the surface and well raked in. Care, however, shall be taken against the use of such manures as have seeds of objectional grasses or weeds. Before placing the loam the surface of the slope shall be loosened up roughly to insure a good bond. The surface of the slope to be sodded shall be laid out in shallow horizontal trenches 12 in apart and 3 in deep. The Bermuda sod shall be separated into tufts or small pieces not more than 4 in square and applied in trenches at intervals of 6 in to 1 ft apart, according to quality of sod and character of soil, the object being to place only enough of old sod to furnish enough creeping stems to cover the slope in a reasonably short time, thus creating a new sod on the slope in preference to the old sod. The top of the sod shall not extend above the surface of the slope, and if the season is advanced so that it is liable to have hot weather or freezing weather, the sod shall be depressed just below the surface and a covering of loam placed over the soil and loose earth packed firmly around the sod.

"Sod laid during the day shall be thoroly watered as soon as practicable after laying and no sod shall be left over night not laid without water. All sod shall be watered daily for 20 days after laying when necessary. On slopes steeper than 2 to 1, the sod

shall be in narrow strips 3 to 4 in wide and 3 ft long and shall be staked to the bank with small stakes 8 in to 1 ft long, stakes being placed every 1½ ft apart. After the slope has been filled sod shall be rolled or firmly padded down with shovel to a smooth uniform surface. All sod must be taken from good rich soil, be uniform in texture, free from objectionable grasses or weeds and in good healthy condition with no signs of decay and must contain sufficient moisture to maintain its vitality during transportation.

"Sod shall preferably be cut 3 ft or more long and 1½ to 2 ft wide and not less than 2½ in thick, large pieces of sod being preferable on account of containing their moisture and standing transportation better than small pieces. Sod shall be as fresh as possible and received on the work daily, and any sod to be left over night shall be thoroly watered; and sod that is heated will not be accepted. All sodding shall be finished before the continued frost sets in.

"Sod shall be paid for as measured in place, and shall include the entire surface sodded, this price to include furnishing of sod and handling of same. Transportation of sod, men and material also to include stakes where it is necessary to stake the sod. The entire work shall be done in a thoro, workmanlike manner to the end that the appearance after completion shall be as nearly as possible that of good natural growth in place.

"Objectionable grasses and weeds shall be removed from time to time to prevent shading the grasses until such time that the sod has taken hold or the creeping stems have covered the entire slope.

"Where springs have developed on the slope, a blind drain of cinders or broken stone shall be laid from spring to the toe of the slope."

Am. Ry. Eng. Assn. Recommendations Relative to Slides (18). "Each slide should be considered as a problem by itself. The cause of the slide should be sought. The removal or prevention of the cause is as important as the restoration of the roadway. Piles or retaining walls for the prevention and cure of slides are not recommended; but their use is permissible for temporary repairs and in special cases. Underground water should be drained away or intercepted before it reaches the slide. The surface of the slide and the restored roadway should be graded so that water will run off and not lie in pools. The surface may be compacted or sodded. The flattening of the slope is the most economical and permanent method of curing a sliding embankment. The weighting of the toe of the slope to restore equilibrium may sometimes be found efficient. The removal of the material is nearly always the most economical and permanent method of curing a slide in excavation."

3. Subgrades

The subgrade consists of the upper surface of the native foundation on which is placed the road metal or the artificial foundation, in case the latter is provided. The subgrade is thoroly compacted by rolling to conform to the lines and grades. All muck, quick-sand, soft clay, or spongy material which will not consolidate under the roller, is removed to such depth as is necessary and the space refilled with suitable material from excavations or with other materials such as earth, gravel, or broken stone. All hollows or depressions which develop in rolling are filled with suitable material and the process of filling and rolling is repeated until no depressions develop.

Penn. Highway Dept. Specifications Covering Construction of Subgrade. "The bottom of the excavation and the top of the fill when completed, shall be known as the subgrade and at all places shall be true to the lines, grades, and cross-sections as shown on the plans. All work in connection with the preparation thereof will be included in the contract price for excavation or borrow.

"Construction of Subgrade. The subgrade shall be brought to a firm, unyielding surface by rolling the entire area with an approved 3 wheel power roller, weighing not less than 10 tons, and all portions of the surface of the subgrade, which are inaccessible to the roller, shall be tamped thoroly with a hand tamper, weighing not less than 50 lb, the face of which shall not exceed 100 sq in in area. All soft and yielding spots and all vegetable substance or other unsuitable material, shall be removed

and the space refilled with approved material. In plowing for the lowering of the old grade, care shall be taken not to plow below the finished grade of the new subgrade.

"PROTECTION OF SUBGRADE. In handling materials, tools, equipment, etc, the Contractor shall protect the subgrade from damage by laying planks thereon, when directed and shall take such other precautions as may be deemed necessary.

"ACCEPTANCE OF SUBGRADE. No foundation or surfacing material shall be deposited until the subgrade has been checked and accepted."

III. Practice Covering Construction of Subgrades on Different Types of Soil (18). "With respect to their properties of shedding or absorbing surface water all characters of soil encountered in Illinois road work may be assigned to one of the three following classes: (1) Impervious soils, such as the prevailing gumbo thruout the corn belt, or any dense clay or other soil thru which surface water will not readily penetrate; (2) semipervious soils, those soils of an intermediate character that evidently are not assignable to either class 1 or class 3; (3) very porous soils, including sand, gravel or loose stone; soils thru which surface water will readily penetrate. In case of doubt as to whether a particular soil should be assigned to class 1 or class 2 it should be assigned to the former, and for doubt between classes 2 and 3 the assignment should be made to class 2.

TREATMENT OF EACH CLASS OF SOIL. (1) "No matter whether on an elevated tableland or on a low bottom, where the obtainable side-ditch grade is less than 0.4%, not more than 800 ft of road in one stretch should have the crown of its subgrade (finished crown for earth roads) less than 12 in above the general elevation of the adjacent land without the limits of the right-of-way, notwithstanding the size of the side-ditches. Exceptions to this rule would be where the highway follows a practically level ridge and the adjacent land drains away from the road on both sides: also, where the highway follows along land that all drains one way. In the latter case, needless to say, cross-culverts should be placed at suitable intervals to carry the water from the higher ditch to natural outlets. (2) Same as class 1, except that 0.2% should be substituted for 0.4%. (3) The crown of the subgrade should be at least 6 in above the general elevation of the adjacent land without the limits of the right-of-way.

"Notwithstanding the character of soil, where the grade of the side-ditches is from 0.4 to 1% an endeavor should be made to keep the crown of the subgrade at least 6 in above the general elevation of the adjacent fields. With a non-porous soil and an open-ditch gradient of less than 0.4% it is difficult to provide surface road drainage by seeking natural channels located at considerable distances apart. A more effective and more positive practice is to elevate the road-bed by filling from borrow pits to an elevation above the accumulated water level, which under the conditions assumed is the general level of the adjacent fields."

4. Grading Machinery, Methods of Use and Cost Data

Considerations Affecting the Purchase of Machinery. The purchase of an ideal equipment will be justified and is usually advisable if the work is to be extensive in character. As a fundamental economic principle, maximum use should be made of time and labor saving machinery, due especially to the ever increasing cost of common, as well as skilled labor, and the incidental charges entailed by its employment. Highway departments and contractors are necessarily forced to consider first cost of equipment as the funds available may not permit the installation of the most economical and efficient machines. In many cases where such conditions are encountered, it is obvious that it will not be practicable to anticipate that the work can be accomplished with the same degree of rapidity and at the same cost, as if more efficient machinery constituted the plant equipment.

Before purchasing a special type of machine which has been designed with a view of reducing to a minimum the cost of a certain class of grading, the probable scope of work to be carried on by a department or contractor should be analyzed to determine if the amount of one kind of grading work will warrant the purchase of the special machine or if, in the long run,

such work should not be done with more ordinary types of machines at a slight increase in cost.

Depreciation charges on plant equipment always should be given careful consideration prior to the purchase of machines and accessories as well as in estimating the cost of highway work. The larger types of grading machinery usually must be used for a considerable percentage of the working season, as otherwise such overhead charges as interest on first cost, cost of housing or storage, painting, etc, will be prohibitively high when applied to the cost of a unit of grading on a given piece of work.

If an organization does not include men who are specialists in the manipulation of complicated machinery or if skilled labor is not economically available, simplicity of machines and ease of manipulation should be given great weight in the selection of equipment. For example, common labor may efficiently perform grading work with scrapers, shovels, wagons, etc, while skilled labor will be required to operate a steam shovel or an elevating or traction grader. Again, graders may be hauled by animals driven by ordinary labor, while, if traction engines are employed, skilled labor must be utilized.

Upkeep of Equipment by Hauer (40c). "When a new machine is purchased, there should always be bought at the same time a number of spare parts, which should be kept on hand to be used as needed. No man can build a machine that will not break down in some vital part sooner or later. A breakdown in a construction job means not only a delay, but a waste of money, for even if men can be laid off and not paid, or can be given other work, yet the job, due to the changes made necessary by the breakdown, will not be worked in the most economical manner. It is true that many contractors do keep some spare parts, but they seldom have on hand enough, or the proper ones, due to the fact that as the parts are used to replace broken ones, new ones are not ordered from the factory. Then either one of two things occurs: The job is shut down or some part of it, or the machine is worked with the broken part until a new one can be ordered and put in place. This means that the machine is racked by the work it does, doing permanent injury to it. A good blacksmith shop on the job, equipped with forge for heating heavy steel and with stocks and dies for bolts and pipe, and with good drills and vises, will be found to be a great assistance in the upkeep of road equipment. For heavy machines a few roller bearing or small hydraulic jacks will be found useful in making repairs and renewals.

"Small tools can be repaired promptly in a blacksmith shop. Attention should be given to these as well as to the larger machines. To prevent such tools being lost, they should not only be branded with a die of the contractor's name or initials, but they should likewise be painted with a set of colors, selected by the contractor, to designate his equipment and advertise his business. These colors can be used on the head of some tools, and in most cases on the handles. Tools cannot be thus stolen or lost. All bright parts of tools and machines that cannot be painted should be well greased so as to prevent rusting."

Life of Road Construction Equipment (31c). "The Ariz. Highway Dept. has adopted an equipment depreciation table to be used in cost estimating. The table is as follows:

	Annual Depreciation
Steam shovels	10%
Engines, gas or steam	20%
Concrete mixers	20%
Rock crushers	20%
Pile drivers	20%
Graders	20%
Plows	20%
Wagons and harness	20%
Mules	10%
Wheelbarrows	50%
Concrete carts	50%
Fresno scrapers	100%
Tents	75%

"In calculating depreciation and repairs, it is usually desirable to separate the two. Estimate depreciation for the full years, but estimate repairs

by the month of actual work. Thus, in the case of a steam shovel, the annual depreciation may be estimated at 6%, and the repairs may be estimated at 2% per month of single-shift work. Then if it is estimated that the shovel will actually work 6 months during a year, the depreciation amounts to 1% and the repairs 2% per month of actual work. Roadbuilding equipment averages less than 6 months' actual work in the northern states, probably about 4 months. This runs up the interest and depreciation charges per month of actual work. Thus, with annual interest at 6% and depreciation at 12%, there will be 18% for the year, or 4.5% per working month if charged entirely against the working time. Add to this, say, 2.5% for repairs, and the total will be 7% per working month for interest, depreciation and repairs."

Small Tools. Picks. The pick may be pointed at both ends, or it may have one end flattened to a chisel point for use in trimming up slopes of cuts. The pick head weighs from 7 to 9 lb and is made of a high grade steel, the points being made of crucible tool steel. An average price per dozen for pick heads is about $6. Pick handles cost from $1.50 to $3 per dozen, depending upon the selection and finish of stock.

Shovels. A pointed shovel with a short D handle is the one most commonly used in grading operations in the United States. In Europe the same style of shovel with a long, straight handle is more in favor. Square-pointed shovels are better adapted for mixing either cement or bituminous concrete, and for handling sheet-asphalt mixtures. Scoop shovels are used to advantage in street-cleaning operations, for handling sand or other fine material, and for removing snow. Shovels are made in different sizes and of different grades of steel, the blades having either a black or a polished finish. The following table (31b) gives prices for shovels with black-finish blades. Shovels with square or round points with D or long handles are the same. A No. 2 shovel is the size generally used. For a polished finish add 50 cents:

Size	Width of Blade, Inch	Length of Blade, Inch	Extra Grade per Dozen	First Grade per Dozen	Second Grade per Dozen	Third Grade per Dozen
2....................	9½	11¾	$9.90	$8.70	$7.20	$5.70
3....................	9¾	12¼	10.20	9.00		
4....................	10½	12½	10.50	9.30		

Mattocks and Bush Hooks. Mattocks are used mainly for trimming up slopes, for loosening soils full of roots, and around stumps. The heads weigh about 6 lb each and the average price is about $4 per dozen. Handles are the same price as pick handles. Bush hooks are used mainly in clearing away brush and small undergrowth.

Brush Scythes (27a). "For cutting down small brush a brush scythe should be used, not a brush hook as is often done. With the hook or an axe the man using it must grab each piece of brush with one hand and hit it with the hook to cut it off, while with each stroke of the scythe from two to a dozen pieces of brush can be cut down. Some brush, however, is too heavy to be cut with a scythe, and then it is necessary to use a brush hook. For large saplings and trees an axe must be employed."

Hoes and Rakes. Hoes and rakes are principally used in shaping up the surface. Hoes are also used in street-cleaning operations. The price of hoes is about $6 per dozen with 6-ft handles.

Wheelbarrows. Wheelbarrows are made of wood, steel, or with a wooden frame and steel bowl. The wooden form is more commonly used in Europe and possesses the following advantages over those built with a steel bowl

or all steel. (1) It is cheaper; (2) it is more cheaply kept in shape and is much better adapted for quarry work, where a steel bowl is liable to become much abused by having stone thrown into it; (3) it is somewhat lighter than the other two. On the other hand, if it is desired to handle a semifluid material or a concrete or bituminous mixture, a barrow with a steel bowl will serve the purpose much better. The weight of a wooden wheelbarrow is about 60 lb and of an all-steel barrow 75 to 80 lb. They are made in different sizes, those having a capacity of 3 to 4 cu ft being generally used. The price of a wooden wheelbarrow is about $2; one of all steel about $7.

Carts and Wagons. A one-horse tip-cart is generally built with 2 wheels. The body tips over the axle in discharging its contents. The bodies, without side-boards, have a capacity of about 21 to 24 cu ft. The average cost is about $50. Two-horse tip-carts are operated on the same principle, but are built on 4 wheels. They hold about 1½ cu yd of material, loose measurement. They cost between $50 and $75. Patent bottom dump-wagons are made in 1, 1½, 2, 2½, and 3 cu yd sizes. The bottom of the wagon is made up generally of 2 leaves, hinged either to the sides or to the ends of the box. The doors are held in place with chains which are wound up on a windlass, operated by the driver. To dump the load, the driver with his foot kicks a release lever and the doors fly open, thus discharging the load. The doors are closed by the driver turning the windlass. While the body of the wagon is generally made of wood, the bottom doors are sometimes made of wood and sometimes of sheet-iron. One of the doors is usually provided with a lip, which overlaps the joint formed by the doors, and thus prevents the material from sifting thru. The price of wagons of this type varies from $25 to $200, dependent upon the capacity.

Comparisons of Wagons by Ellis (30). "Four kinds of wagons have been used on road building, the 4-wheeled bottom dumping wagon, 4-wheeled 2-horse tip cart, the 2-wheeled 1-horse tip cart and the 4-wheeled slat wagon. The slat wagon offers no advantages except that it is a little lighter, lower and easier to load; this advantage is outweighed when the time lost in dumping and turning around is taken into consideration. The 1-horse tip cart is economical on short hauls and for work in a contracted space, for making end and side dumps on embankments or for short hauls of stone to crusher. The 4-wheeled tip cart hauls and is handled very easily on road work, but the weight being on the rear wheels it is very destructive to the road surface and subgrade and much time lost in dumping and righting the wagon. The bottom dumping wagon can be used anywhere that the other 2-horse wagons can be used and is more economical than either. The expense of maintaining the roadway is very much less than with the tip carts. Material can be dumped more quickly, it not being necessary to stop while dumping and the material can be distributed to better advantage than with the other types of wagons. Any wagon used on road work should have tires not less than 4 in wide."

Road Drags. See Sect. 9, Art. 14.

Plows. The grading plow is so made that the furrow may be turned either to the left or to the right. The function of the shoe or wheel near the front end of the beam is to regulate the depth plowed. An ordinary grading plow will make a furrow about 10 in wide and from 6 to 12 in deep. The price of grading plows varies from $15 to $30. For breaking up hardpan, old macadam, or other stiff material, a rooter plow, as illustrated in Fig. 1, is employed. A plow of this kind is generally pulled by a steam roller or a tractor. If horses are used it may require from 6 to 12, depending upon the material plowed. The cost of rooter plows varies from $30 to $40.

Fig. 1. Rooter Plow

Drag Scrapers. A drag scraper, as shown by Fig. 2, consists of a pressed steel bowl to which a bail and handles are attached. They have capacities from 3 to 12 cu ft. These capacities, however, are figured on the basis of loose measurement and for a scraper heaped full. This form of scraper wears out very rapidly on its cutting edge and on the bottom, particularly when working in hardpan or gravel. The price of drag scrapers ranges from $5 to $15.

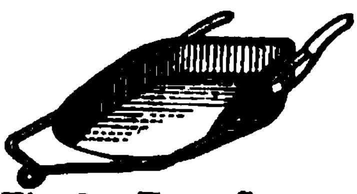

Fig. 2. Drag Scraper

METHOD OF OPERATION. A drag scraper is usually drawn by 1 or 2 horses. To load, a man grasps the handles and pushes the cutting edge down into the loosened earth as the scraper is pulled along. Then the full scraper is dragged along on its bottom to the point of dump, where either the driver or a dump man takes hold of one or both of the handles and lifts the scraper so that it turns upside down about its cutting edge.

The Fresno or Buck Scraper as described by Frickstad (35a). "It consists essentially of a pan, open in front, with vertical sides and back to hold the earth. To the back is attached a handle, and to the handle a piece of rope for convenience in manipulation. When loaded the scraper slides on the pan, but when empty the pan tips up and rides on runners to save wear and to evade irregularities in the ground. Two, four, or six horses are used, four in a great majority of cases. The capacity of a 4-horse Fresno is 6 or 8 cu ft, as computed by multiplying the width by area of the ends, but the amount moved depends upon the character of the earth, the manner of manipulation, and the hauling ability of the horses. It may occasionally be less than the amount indicated, and is frequently more than 1 cu yd, if the earth is moist and adhesive enough to pile up and to push ahead of the scraper. The usual practice is to operate the scrapers in runs of 3 to 8, according to length of haul. The Fresno is generally limited to a haul of 200 or 300 ft, tho of course the nature of the contractor's available equipment frequently modifies that. It requires less time and labor to load and unload than does a wheeler, but the expense of the 2 extra horses balances these items when the haul exceeds 200 or 300 ft. It is especially useful on highways, on light railroad work, on irrigation and drainage ditches where the cut makes the bank or is wasted, and for loading large cuts into cars thru a trap. A steep downhill haul, far from being a difficulty adds tremendously to the yardage handled, if not too long. Records range from 28 to 130 cu yd per scraper per day.

"Following is a record made under most favorable conditions, in Jan., 1904. Weather, clear and cold; soil dry, breaking readily, being loam, sand and clay in irregular beds; earth moved from ditch to make the base of both banks of canal, extreme lift being about 10 ft; a small amount of earth hauled as much as 200 ft:

Foreman, 15 days at $4.50	$ 67.50
Four-horse Fresno and driver, 84 days at $5.30	445.20
Six-horse plow, driver and holder, 13 days at $9	117.00
Labor, clearing, helping plow holder, etc, 30 days at $2	60.00
Labor, loading scrapers, 32 days at $2	64.00
	$753.70

Engineer's estimate, 10 219 cu yd. Deducting $38 as the cost of clearing, the cost per yd was 7 cents. It shows 122 cu yd moved per scraper per day, and it is certain that the average would have been 130 cu yd had all hauls over 100 ft been eliminated.

"Following is a record of extremely difficult conditions. The earth was thoroly mixed with stone, in all sizes up to 5 cu ft. The greater part of these had to be taken to the outer edge of the embankment. The material was hard to plow and harder to load. It was all used in making the banks, mainly on one side, with little longitudinal haul.

Foreman, 16.5 days at $3	$ 49.50
Four-horse Fresnos, 61.5 days at $5.30	325.95
Two-horse stoneboat, 11.2 days at $3.65	40.88
Four-horse plow, etc, 6.5 days at $7.40	48.10
Six-horse plow, 5.2 days at $9	46.80
Labor loading scrapers and stoneboat, 76.2 days at $2	152.40
	$663.63

Estimate 3800 cu yd. Supposing the 11.2 stoneboats to have been equal to 3½ Fresnos this would give 58.5 cu yd per day per Fresno. The cost would be about 17½ cents per yd."

Wheel Scrapers. A wheel scraper, Fig. 3, is similar in shape to a drag scraper, but the bowl is fixed to 2 wheels fitted with a pole and is usually drawn by 2 horses. They have capacities of 9 to 18 cu ft. Scrapers with 4 wheels are also manufactured. The price of this type of scraper varies from $30 to $75.

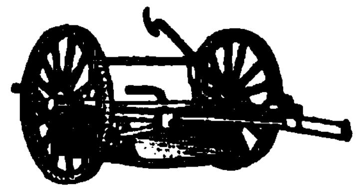

Fig. 3. Wheel Scraper

Method of Operation. A wheel scraper is operated as follows: As it is pulled thru the plowed material in its lowered position, a man grasps the small handles at the rear of the bowl and tilts the bowl so that the cutting edge engages with the earth. When the scraper is full, he pulls down on the long lever at the rear, which raises the bowl from the ground. The lever is locked by a catch and the scraper is hauled to the dump. On the small-size scrapers no snatch team is used; on the medium size a snatch team is generally used; and on the large size a snatch team is always used. A snatch team consists of a pair of horses, which is hitched to the pole in front of the team dragging the scraper during the process of loading.

Cost Data. Lawrence (47) states that: "In one job recently completed (1917), four Baker-Maney 4-wheeled scrapers were used, each of 1 cu yd capacity, using a hoisting engine instead of a snap team for loading the scraper. The total amount of excavation in this job was 4156 cu yd. The dump was about 750 ft way, making the average round trip of the scraper 1500 ft. These scrapers averaged about 40 trips in a 9-hr day. The final cross-sections of the work, when compared with the total number of loads, showed that the average amount carried was just about 1 cu yd per load. The soil was part top soil and part clay and the depth of excavation averaged about 4 ft. The daily cost of moving 160 yd was as follows: 1 foreman, $5.00; 1 snapman, $3.00; 1 hoisting engine, $4.00; 1 engineer, $2.00; ½ ton coal, $2.00; oil and water, $.50; repairs, $.35; 4 scrapers, 1 cu yd capacity, $28.00; 1 plow team, $7.50; 1 plow man, $3.00; depreciation on 4 scrapers, $6.00; total cost per day, $61.35. This gives about 40 cents a cu yd. This cost could have been reduced by using two more scrapers on the work, as the four scrapers did not keep the loading engine busy, and the plow team could have loosened from 350 to 400 cu yd per day."

Table I.—Cost of Excavation of Loam and Clay with Four-Wheel Scraper (48)

2 fireman, at $3	$6.00
1 cableman	2.00
7 teams and drivers, at $5	35.00
Total cost of labor per 10-hr day	$43.00
Cost of labor per cubic yard excavated, $43/800	0.053
1 traction engine and operator	16.00
Cost per cubic yard excavated, $16/800	0.02
Supervision and general expenses	3.00
Interest on investment (7% of $1800)	0.62
Depreciation, based on 5-year life	0.88
Repairs, estimated	1.00
Total general and overhead expenses	$5.50
Cost per cubic yard excavated, $5.50/800	0.007
Total cost of work per day	64.50
Total amount of excavation, cubic yards	800
Cost of work per cubic yard excavated, $64.50/800	0.08

Light Street Grading in Chicago, as described by Stivers (58). "The grade of the streets is usually a little above that of the flat adjoining land. A cut of 1 ft to 18 in has to be made, removing the old earth road and bringing the grade down to 7 in below the inside upper edge of the gutter. On some of the streets many of the adjoining lots are unimproved and the excavated material can be spread over them, bringing them up to the sidewalk grade. On others, the earth must be carried several blocks before it can be wasted. The outfit consists of a run of 5 Maney 4-wheel scrap-

ers, loaded by a 10-ton Buffalo-Pitts steam roller of the macadam type. The Maneys bite into the old earth roadway easily, taking an unusually full load at each trip. The roller has plenty of power and loads the scrapers with seemingly little effort. The loaded scrapers are driven onto adjoining lots and dumped to spread the material to a depth of about 1 ft."

U. S. O. P. R. Comparison of Grading with Drag Scrapers, Wheel Scrapers, and Wagons (50). "The choice of proper implements to employ in moving material from excavation to embankment depends, first, on the nature and quantity of the material to be moved, and, second, on the length of haul. In general, where the material consists of earth it is loosened with plows and the economical method of hauling is fixed by the haul length about as follows: For lengths of haul not exceeding 150 ft, drag scrapers; for lengths of haul between 150 ft and 600 ft, wheeled scrapers; for lengths of haul above 600 ft, wagons. Where the material consists of solid rock it must be loosened by drilling and blasting and practically always is hauled in wagons or carts, regardless of the haul length.

"Drag Scrapers. In operating drag scrapers the drivers also may load and empty the scraper, but frequently it is economical to provide additional laborers for this purpose. With a haul length of 100 ft and the teams moving steadily, 1 laborer should be able to load or empty and spread the material for about 3 scrapers. For scraper work to be effective the material to be excavated must be thoroly loosened by the plows and should be free from large roots or stones. Where such obstructions occur time is saved by having them removed by hand during the progress of the plowing.

"The average small organization for carrying on road-grading work with drag scrapers is made up about as follows. Force: 1 foreman, 4 to 6 scraper drivers, 2 laborers for loading scrapers, 2 laborers for dumping and spreading, 1 driver for plow, 1 laborer to hold plow, 1 laborer for trimming shoulders, etc, 4 to 6 two-horse teams for scrapers, 1 or 2 two-horse teams for plow. Total, 1 foreman, 14 laborers, and 7 teams. Tools: 6 drag scrapers, capacity 5 cu ft, 1 road plow, 2 picks, 2 axes, 2 mattocks, 3 shovels. The force employed should vary somewhat with the haul length, which is usually between 25 and 150 ft. Under average conditions an organization such as that described above should move from 300 to 350 cu yd of earth per 10-hr day.

"An objectionable feature of drag-scraper work is that the embankments tend to settle very irregularly. The reason is that the successive loads are not spread out uniformly as they are dumped, but are deposited as a succession of rather compact cores with the intervening spaces consisting of comparatively loose material. The loose material settles more than the compacted spots, and this unequal settlement produces pockets in the surface which hold water and gradually become deepened under the action of traffic. Where the material to be moved is loose and light, such as the prairie soils of the Middle West, this objection can be overcome largely by substituting Fresno or Buck scrapers for the common type of drag scrapers. One of the principal advantages of Fresno scrapers is that the runners may be adjusted to spread out the load to any desired depth from 2 or 3 in up to 12 in and this better distribution of the material in the embankment tends to prevent inequalities from developing in the finished road surface.

"Wheeled Scrapers are used to a greater extent in road grading than either drag scrapers or wagons. The reason for this is that in road work the haul length falls, more frequently than otherwise, within the limits for which wheeled scrapers are economical.

"A small organization for carrying on grading work with wheeled scrapers may be made up about as follows. Force: 1 foreman, 6 to 11 drivers, 1 laborer for plowing, 2 laborers for loading scrapers, 2 laborers for dumping and spreading, 1 laborer to trim slopes, etc, 1 two-horse team for plow, 4 to 8 two-horse teams for scrapers, 1 or 2 two-horse snatch teams. Total: 1 foreman, 17 laborers, 11 teams. Tools: 8 wheeled scrapers, capacity 11 to 15 cu ft, 1 road plow, 2 picks, 2 mattocks, 2 axes, 3 shovels. The force employed should vary with the haul length, usually from 150 to 600 ft. Six to eight scrapers should be employed where the haul exceeds 250 ft. Where necessary one of the snatch teams may be used to assist the plow teams. Such an outfit should move from 200 to 250 cu yd of earth per 10-hr day.

"Where wagons are used for hauling and the excavation is fairly light, it is customary and economical to loosen the material with plows and to load it into the wagons

with hand shovels. If the excavation is fairly heavy and sufficient in amount to warrant the additional outlay, it is economical sometimes to employ a small steam shovel for loosening and loading the material. The steam shovels used ordinarily in road work have a dipper capacity of from $\frac{1}{2}$ to $\frac{3}{4}$ cu yd. Under fairly favorable conditions steam shovels of these sizes can be made to load from 400 to 500 cu yd of stiff earth per 10-hr day. Where the material is loosened by means of plows and hauled in wagons, the average small grading gang may consist of 1 foreman, 3 laborers and 2 teams for plowing, 9 laborers for loading, 2 laborers for spreading, and a sufficient number of teams for hauling to keep the above force busy. With such a force the number of wagons for maximum efficiency varies from about 3 for a 500-ft haul up to about 12 for a haul of 1 mile. Ordinarily, one of the plow teams may be employed in hauling for at least a part of the time. Under average conditions such a force as that described above should move about 150 cu yd of earth per 10-hr day."

Road Graders. There are several different types of road graders. The 4-wheel machines, Fig. 4, have blades from 7 to 8 ft long, made up of two parts, a cutting edge and a mold board. The blade is suspended from a part of a full circular frame attached to the machine. By turning the large wheels the blades may be tilted at any desired angle with the vertical. It is also possible to turn the blade thru any desired horizontal angle. In some types of machines the blade is given a forward or backward tilt by attachments fixed directly to the blade, while in others the blade is fixed in this respect, and the tilt is obtained by lowering or raising the front end of the frame over the front axle. It is also possible in some types to shift the blade sideways so as to project beyond the wheels for some distance, which is a great convenience in filling in ditches or cutting down banks. The framework is generally made of steel shapes, altho wood is sometimes used. Another feature of many of the 4-wheel machines is that the rear axle is made telescopic so that either wheel may be shifted in a lateral direction. This adjustment enables the rear wheels to straddle a furrow or to engage with the side of the banks and thus prevent side slip. In some makes the rear axle is pivoted so that it will turn thru a small horizontal angle, helping the machine to keep in place when in the center of the road. There are some types also in which the rear wheels are so fixed to the axle that they may always be made perpendicular to the slope on which the machine is travelling. All of these different adjustments are carried out by one man, who stands on the rear of the machine and operates the various wheels and levers, all of which are within easy reach. A 4-wheel machine weighs about 3000 lb, and the price varies from $200 to $300. Various types of 2-wheel scrapers are also manufactured which weigh from 600 to 800 lb. The price varies from $150 to $175.

Method of Operation. In grading by means of a scraper the dry grass and sod is first burnt off. A cut is then made at the edge of the ditch, using the point of the blade, the latter being set at a sharp angle so that only the point and a very short length of the blade come in contact with the ground. On the next round the blade is lowered to a flatter angle and the earth is moved along the blade toward the center of the road. By making several rounds of the scraper in this manner the road-bed is crowned up at the center. To smooth out the road-bed, the surface is first thoroly

harrowed to break up the large lumps, and then the scraper is drawn along the road with the blade set at right angles to the center line of the road. When a reversible machine is used the blade is turned around so that the convex side is ahead. A plow is not necessary in scraper work, since the machine can generally do all the plowing desired with the point of the blade. In order not to get a soft road it is not advisable to move the earth up with the scraper in layers over 4 in deep. In some cases from 1 to 3 furrows are plowed at the ditch side of the road, the material being turned toward the center. The scraper is then set to work at the furrow nearest the center, and it moves over from this furrow toward the center only about as much earth as is loosened by the first round of the scraper. The next furrow is moved over in a similar manner, and the process is repeated until the last furrow is reached, which is moved over in turn. The road is then smoothed out. The 4-wheel machines for heavy work require from 4 to 6 horses, whereas 2 horses are used when the work is light. On the lighter 2-wheel machines from 2 to 4 horses are necessary, depending upon the character of the work.

U. S. O. P. R. Directions Covering Use of Road Graders (50). "Before any machine work is done the area to be graded should be either burned or mowed over so as to remove all grass and weeds. The grading then should proceed as follows:

1. Set a row of stakes, 100 or 200 ft apart, along the inside edge of each side ditch. The purpose of these stakes is simply to aid the driver in making the initial furrow of the machine conform with the line of the road, and since the stakes are destroyed by the first furrow they need be only sufficient to serve this temporary purpose.

2. Set the blade of the grading machine at an angle of about 30° with the road, so that the material loosened by the cutting point of the blade will be moved in toward the center of the road; also lower the cutting point and raise the heel, so that the blade will plow an initial furrow about 6 in deep and about 18 in wide. Then make the initial trip with the point of the blade cutting about 18 in outside of the stake line and the outside rear wheel of the machine against the face of the furrow. The material loosened by the first furrow then will escape under the blade in a ridge just inside the stake line.

3. Readjust the machine so that when the outside horses follow the initial furrow in making the second trip the blade will cut a new furrow of somewhat less width than the first and the outside rear wheel will follow the face of the new furrow. Then make successive trips with the machine adjusted in this way until the outside edge of the side ditch is approached, except that after each two trips it is well to rest the team by readjusting the blade and pushing the loosened material over toward the center of the road. For this latter work the blade may be set at a greater angle with the road, and the heel should be lowered and the point raised, so that the cutting edge will conform closely to the crown of the road while the machine is in operation.

4. Repeat the above described operation, omitting the stakes and beginning about 18 in farther from the center each time, until the side ditches are excavated to the required depth and the road is approximately to the required cross-section.

5. Bring the outside faces of the side ditches to a uniform slope by making one or two trips of the machine with two wheels, one front and one rear, on the bank and the cutting edge of the blade against the slope.

6. Make several trips over the road, cleaning out the ditches and smoothing up the surface. The last few trips should be made with the blade reversed, as this method tends to produce a better compacted surface. But, in any event, it is necessary that during the first few months after the grading is completed the road surface should be kept smooth while it is being compacted under traffic. To do this may require frequent use of the grading machine or the drag."

Elevating Graders. The principal parts of the elevating grader, shown in Fig. 5, are the plow and mold board and the elevating belt. A disk plow is sometimes substituted for the pointed plow. The mold board back of the plow is shaped so as to deliver the furrow to the elevating belt

with as little loss as possible. The elevating belt carriers are made in 3 to 5 ft sections, so that any length from 15 to 30 ft can be obtained in some of the larger machines. The carrier is run either with gears driven by the wheels or by a gasoline engine set on the rear of the grader. When the carrier is driven by an engine it requires less power to haul the machine. The price of an elevating grader is about $1000.

Fig. 5. Elevating Grader

METHOD OF OPERATION. For heavy work the grader requires 12 horses, 8 being hitched in front and 4 in the rear, 2 drivers and 2 operators on the machine, who operate the various levers controlling the movements of the plow and belt. A 25-hp traction engine may be used in place of the horses. The grader, as it moves along, plows up the earth, which is thrown onto the elevating belt and discharged over its end, either onto the road or into wagons. See Sect. 9, Art. 10.

Table II.—Comparative Costs of Excavation of Earth with Elevating Grader with Animal Power and Gasoline Tractor (48)

ANIMAL POWER		
7 teams, at $2.50	$17.50	
2 drivers, at $2.50	5.00	
1 operator	3.00	
Total labor cost		$25.50
Interest on investment at 6%	$1.20	
Depreciation, based on 10-year life	2.00	
Repairs and general expenses	1.30	
Total general expenses		4.50
Total cost for 10-hr day		$30.00
Excavated per day		800 cu yd
Cost per cubic yard		3.75 cents
GASOLINE TRACTOR		
1 engineer	$5.00	
1 operator	3.00	
Total labor cost		$8.00
Gasoline, 30 gal at 15 cents	$4.50	
Cylinder oil, 1½ gal, at 36 cents	0.54	
Grease, 2 lb	0.20	
Repairs, waste, etc	0.76	
Total power cost		6.00
Interest on investment at 6%	$2.40	
Depreciation, based on 10-year life	4.00	
Repairs and general expenses	1.60	
Total general expenses		8.00
Total cost for 10-hr day		$22.00
Excavated per day		1000 cu yd
Cost per cubic yard		2.2 cents

Traction Turbine Grader (31g). "The machine moves forward under its own power, digs the road-bed to grade and elevates and loads the spoil into trucks or wagons. The digging action is accomplished by a rotating cylinder, on which are mounted 12 buckets. On the cutting edge of these are rooters, which dig out the material, tumbling it back into the buckets which elevate and dump it on the belt conveyor, extending at right angles from the sides of the grader in position to discharge the material directly into wagons, trucks or cars. While the digging wheel is in action the entire machine moves forward at any of three speeds, according to depth of cut and character of ma-

terial. The weight of the grader is carried on two sets of multiplanes, which do away with planking and prevent settling. The machine is built to dig and load from 60 to 100 cu yd per hr. On some jobs it is estimated that the excavation can be done at a cost of 3 cents per cu yd. For an 8-in cut in old macadam, the cost of digging and loading this material into trucks was about 4 cents per cu yd."

"Elevating Grader for Trench Work (32a). A machine specially designed and built for street-grading work, practically a heavy shallow-trench traction digger, is now in operation in Chicago. In this equipment, the excavating unit, a vertical flight of heavy digging buckets, carried on a triangular frame, is mounted on the rear of a long 4-wheeled truck. At the top, the flight of digging buckets has two points of support, carrying it almost horizontally over a transverse belt of steel slats, which distributes the excavated material to either side as required. On the truck is mounted a horizontal boiler with superimposed horizontal engine. The rated capacity of the machine is from 40 to 60 cu yd per hr. Three principal elements make up the equipment, the digging and elevating unit, the distributing unit and the truck, power equipment, traction, steering gear, etc. The digging system embraces a flight of 11 heavy buckets 33 in wide, with an individual capacity of ½ cu ft. This flight revolves so as to dig upward and into the earth, and along the lower side works in an elevator channel of heavy steel plate. The digging buckets are fitted with detachable and renewable teeth and cutting edges.

"METHOD OF OPERATION. The buckets dig a trench 33 in wide, 4 to 36 in deep. The train of buckets is mounted off center, so that the outer edge of the trench is 8 in outside of the tread of the rear traction wheel. This allows digging close up against a curb. The depth of digging is controlled by means of a rack and pinion on each side.

"When digging, the grader moves forward automatically, an eccentric rod from the main countershaft and a dog and ratchet carrying a slow motion down to the rear wheels by sprocket and chains. The machine is driven forward at a speed of from 5 to 20 ft per min, depending on the material. The transverse distributing unit, a belt built of steel cross-slats on rollers 11 ft apart, is mounted so as to be fed by the buckets as they dump, and, moving at about 300 ft per min, shoots the material into wagons on either side. The belt is 18 in wide, and the slats are turned up at both ends so as to form a retaining channel. The conveyor can be run so as to load wagons at either side, as the work may require."

"Elevating Grader for Street-Car Track Grading (31d). This machine is stated to be particularly adapted to grading in connection with street paving work, especially where it is desirable or necessary to haul the earth in dump wagons and where space is limited as in many points. It is also adapted to excavating trenches for street railway tracks. It cuts a strip 8½ ft wide, and will excavate 2 or 3 in deep, or as deep as 5½ ft, the cutting wheel working on a boom being instantly adjustable by a screw raising or lowering. An indicator is provided so that the operator can run true to a grade line. The earth is deposited in dump wagons and the production is claimed to be so uniform that the number of teams each day can be properly proportioned to the length of haul so that there will be not over ½ min lost team time at the machine on each trip."

Tractors or Hauling Engines. There are on the market many types of steam and gasoline traction engines suitable for hauling grading machinery. For many classes of grading work, their use is more economical than the employment of horses or mules. Numerous examples of the work in connection with which they have been used efficiently are cited thruout this Article.

Essential features which should be possessed by a tractor for grading work are as follows: (1) Sufficient power for hauling the several types of grading machines under the variety of conditions on which it is expected it will be used; (2) adequate mechanical strength; (3) simple mechanism enabling it to be easily steered, controlled and otherwise operated; (4) driving wheels of large diameter and of such width as to enable the tractor to operate efficiently on soft ground.

A combination roller and traction engine may be economically used as a tractor for light grading work, scarifying and general hauling purposes,

but where continuous hauling of grading machines is required, the tractor is more economical.

Steam Shovels by McDaniel (48). " The steam shovel is one of the most efficient and universally used of all modern excavators. The original type of shovel with fixed platform has been generally employed in cuts deeper than 5 ft when the yardage was sufficient to warrant its use. Highway construction, however, usually involves the excavation of a succession of light cuts with depths, varying from a few inches to a few feet. Hence the steam shovel has been little used on road construction prior to the advent of the revolving shovel.

" The revolving shovel is a machine of small capacity, light weight, rapid action and easy portability. The principal features of this type of shovel are the full-circle swing and separate hoisting, swinging and crowding engines, the last of which provides for thrusting the dipper forward into the earth and prying up hard materials. Its especial adaptability to highway construction of all kinds has been proved by its efficient excavation of cuts from 6 in to 15 ft, of all classes of earth, and of street pavements and hard road surface materials, and by its ability to operate over grades up to 10%, make cuts to a smooth and uniform grade and side slopes, and load cheaply into wagons, or overcast in sidehill work.

" The average engineer or contractor conceives of the economic field of the revolving shovel as in heavy excavation only. However, the experience of many contractors has clearly demonstrated the efficiency and economy of the use of the revolving shovel in very shallow excavation, such as excavation for street pavement and foundations and the removal of old street surfaces and pavements.

" Output of Shovel. Ordinarily a shovel will be in actual operation about 40% of the working time. Some of the conditions affecting shovel operations are: Character and physical conditions of the soil; presence of obstructions in soil, such as boulders, roots, pipes, old foundations, etc; depth and width of cut; size, make and capacity of shovel; experience and efficiency of operator. Altho it is impossible to state any definite rules governing the capacity and limitations of a revolving steam shovel in shallow excavations, the data in Table III, which have been compiled from various sources, may be suggestive. This table is based on the use of a revolving shovel equipped with ⅝-yd dipper, efficiently operated under average working conditions for a 10-hour day."

Table III.—Performances to be Expected of a Revolving Steam Shovel in Shallow Excavations

Depth of Cut in Inches	Classification of Material							
	Loose Earth		Packed Earth		Hardpan		Pavements	
	Yardage	No. Observations	Yardage	No. Observations	Yardage	No. Observations	Yardage	No. Observations
18....	360	12	280	9	225	3	300	2
12....	300	5	240	7	175	4	250	4
9....	250	3	200	4	150	1	200	2
6....	200	1	150	3	100	1	150	1

Steam Shovel Excavation of Macadam (51). "The shovel used was a 14-B Bucyrus, equipped with a ⅝-yd dipper. This machine is of the traction type and was operated on platforms. The digging was unusually heavy. The material was a hard packed macadam containing a large number of big boulders, running up in many cases to 3 ft in diameter. The cut ranged from 12 to 18 in in depth. Each 20-ft roadway was taken by the shovel in one cut. The ability of the shovel to take a long horizontal direct thrust enabled it to fill the dipper very easily at this depth. As a result even in this shallow digging a 2-yd dump wagon could consistently be filled with 3 swings."

Steam Shovel Grading in Oregon (26). "The cut was made with a side slope of 1 on 1½ and wide enough to give a 20-ft roadway outside the ditch. This cutting gave a yardage per lin ft of road of from 5 to 8½ cu yd. The material consisted of loose boulders, which had slid down the mountainside, overlying in places cemented gravel, cinders, chalk rock and solid ledge. All had to be blasted. The general method of work was to blast and excavate with steam shovel, casting the spoil downhill to form the embankment. The crew working on and about the shovel consisted of an engineman, fireman, a pitman and a wood and water man. The shovel graded 7884 lin ft at an average rate of about 60 ft per day. The total operating cost, including labor, oil, repairs, fuel and lights, but excluding interest, depreciation and overhead charges, was $6480.90, or about 12 cents per cu yd. Finishing behind the shovel was done by hand and it usually took 3 men per day to finish up in good shape. The cost of finishing was 3 cents per cu yd, based on the total yardage handled by the shovel. Blasting ahead of the shovel cost more than solid rock would have cost, because the drills could not be used in all material. In many places coyote holes 6 in in diameter and 20 ft into the bank had to be drilled by hand. Also care had to be exercised in blasting to protect the railway tracks downhill from the grading. The crew ahead of the shovel consisted of from 6 to 12 men, and 1 powerman, who did all the loading and firing. A 60-hole battery was used for firing. The blasting cost including labor, powder, exploders and battery, $11 882.98 or about 22 cents per cu yd, based on the total steam shovel yardage."

Table IV.—Cost of Steam-Shovel Work on Clay and Loam at Minneapolis (48)

1 engineer	$6.00	
2 firemen	2.50	
2 laborers, at $2.50	5.00	
Total labor cost for 8-hr day		$13.50
Coal, ½ ton, at $6	$3.00	
Oil, grease and waste	0.15	
Repairs and overhead charges	1.05	
Total fuel cost		4.20
Total cost of excavating 250 cu yd		$17.70
Cost of excavation of 1 cu yd, $17.70/250		=$ 0.07

Industrial Railways for Grading Work (60). "Numerous advantages are claimed for hauling by industrial railways on contracts of sufficient size to warrant the expense of installation. It is affected very little by the character of the soil or the weather. It can be operated on sand, black soil or clay, and if proper drainage is provided, the hauling operation can proceed during wet periods when it would be impossible to haul by any other method. This regularity of unloading and delivery is a very considerable benefit in reducing the overhead charges and increasing the speed of construction. The subgrade is not injured and materials are kept cleaner. The speed of operation and the large tonnage possible per train recommends this system as particularly economical for long hauls.

"OPERATION. The successful operation of an industrial railway outfit requires the transportation of materials in large daily quantity, which can be furnished only by a most efficient unloading plant. To load the train in a minimum time, storage bins with a capacity of more than one train should be provided from which the cars can be loaded during the time the engine is taking coal and water, or a train of extra cars should be provided and loaded between trips. Provision should be made at the load-

ing terminal for furnishing coal and water to the locomotive quickly. The number and character of cars required on a contract depends on the length of haul, required rate of delivery, methods of construction and kind of power used. If horse power be used the trains will be smaller and cars may be of lighter construction and weight than with steam power. When the materials are dumped on the grade, a comparatively small outfit may be satisfactory by working day and night hauling gangs.

"ECONOMICS. The investment necessary in an industrial railway equipment is heavier than for any other power hauling method. Outfits of track, cars and locomotives may be rented, but the character of the equipment and wearing nature of the work require a high basis for rental, and the price for one season is about 40% of the value in addition to freight two ways and heavy repairs after the return of the outfit. The average outfit for use on large contracts in Illinois road construction should provide for about 5 miles of track. On this basis, the following is an estimate of the approximate cost with the prices of materials, as in 1917, of such an outfit if purchased and the rental cost for one season:

COST PRICE

5 miles built up track, 20-lb rail, at $3550	$17 750
6 switches, at $60	360
4 curves, at $60	240
42 1½-yd cars without brake, at $125	5 250
8 1½-yd cars with brake, at $145	1 160
4 flat cars, at $225	900
Locomotive, 20 hp	3 300
Total	$28 960

RENTAL PRICE FOR 12 MONTHS

5 miles built up track, 20-lb rail, at $2165	$10 825
6 switches, at $24	144
4 curves, at $24	96
42 1½-yd cars without brake, at $67	2 814
8 1½-yd cars with brake, at $81	648
4 flat cars, at $90	360
Locomotive, 30 hp	1 500
Freight two ways	1 800
Probable repairs	500
Total	$18 687

"The operating cost is estimated by the manufacturers at $12 per day, including engineer, brakeman, coal and oil."

Horse Rollers. A horse roller is generally made with one large roller having a face of about 5 ft and a diameter of about 5 ft. Any weight desired from 2½ to 5½ tons, varying by 1 ton, can be obtained. Additional weight may be placed in the boxes at each end of the frame and the weight be thus increased by 1 ton. The roller is made of steel or cast iron. An essential feature of a horse-drawn roller is to have it reversible, so that it can be drawn in either direction. A grooved roller is sometimes specified, due to the fact that better compression can be obtained than with the smooth-faced roller. The grooves are formed by bars bolted around the face of the roller parallel to the edges and at a small interval apart. The price of horse rollers varies from $300 to $450, depending upon the size.

Three-Wheel Rollers. Three-wheel rollers vary in weight from 10 to 20 tons. The majority of rollers of this type are run by steam, altho there are a few makes which are run by gasoline engines. Rollers are generally furnished with a high and low speed. The low speed is used in rolling

embankment, subgrade, telford, etc, while the high speed is used in finishing the surface or in travelling from point to point. The price of three-wheel rollers varies from $2500 to $3500.

Tandem Rollers. The weight of tandem rollers varies from 3 to 12 tons. These rollers are commonly run by steam, altho there are some makes which are run by gasoline engines. The price of tandem rollers varies from $1300 to $3000.

Scarifiers. This machine usually consists of a heavy cast-iron block on 2 or 4 wheels which holds a series of steel picks. The block weighs about 3 tons and the picks can be adjusted in the block or the block itself arranged so that any depth desired up to 5 or 6 in can be picked up. The picks are arranged in either a straight line or in 2 lines which, together, form a V. Most of the scarifiers are so designed that it is not necessary to turn them around. This is accomplished generally by having two sets of picks, one set being used when the machine runs in one direction and the other when in the opposite direction. Scarifiers of this type are towed by a chain hitched to the roller. The arrangement of the picks and the form of the blocks vary, but all of the machines work on the same principle. An average price of block scarifiers is $500. Another type of scarifier consists of a series of 5 to 10 spikes attached to a block weighing from 500 to 3000 lb and which is suspended from a frame similar to that of a road grader. The row of picks is on an angle with the longitudinal axis of the machine. This type of scarifier is hauled by tractors or horses, dependent upon its weight and the character of the surface to be scarified.

Watering Carts. In the United States the cart used for sprinkling generally consists of a cylindrical tank mounted horizontally on a 4-wheel truck. The tank may be made either of wood or of steel. The capacities vary from 350 to 1000 gal. Carts with horizontal valves throw the water out in horizontal sheets, while those with vertical valves distribute the water in vertical sheets. The average price of a 600-gal watering cart is $350.

U. S. O. P. R. Methods of Estimating Cost of Grading are as follows (50): "The cost of grading varies greatly, according to the condition of the weather, the nature of the material to be excavated, the efficiency of labor, teams, and machinery, etc, and seldom can be estimated in advance with any great degree of accuracy. On this account average costs based on past experience may be very misleading when applied to a particular project. In the following statements and data, an effort is made to show the approximate range of cost rather than the average.

"The first step in estimating the cost of grading a given road is to ascertain the quantities of work to be done. After the quantities have been determined the cost may be estimated in either of two ways: First, the organization for carrying on the work may be planned in detail and the estimate arrived at by considering the cost of maintaining such an organization, together with the rate at which it may reasonably be expected to accomplish the work. Second, the cost per cubic yard for excavation and the cost per mile for shaping the roadway may be estimated at flat rates. The first method is the most accurate, tho the latter is the one employed most frequently.

"If the prices for labor and teams are known, the cost of grading under a given set of conditions may be estimated from the data already given. A frequent source of error in estimating costs in this way is that such items as supervision, lost time for which payment must be made, repairs to tools and machinery, and depreciation of the plant are overlooked. The following data (see Table V) are intended to furnish a rough guide in making estimates of grading cost at a flat rate per cubic yard. They are based on labor at 15 cents per hr; horses at 12½ cents per hr. The depreciation of grading equipment and repairs are figured at 5% per month while in use, and it is expected that the force will be organized economically and managed efficiently."

Table V.—Cost of Excavation and Embankment

Kind of Material	Aver. Haul	Method of Hauling	Average Cost per Cubic Yard	Remarks
	Feet		Cents	
Light sandy loam, free from roots, etc.	50	Drag scrapers	10 to 15	Materials assumed to be such that little or no plowing is necessary
	100	Drag scrapers	12 to 20	
	300	Wheeled scrapers	16 to 25	
	1000	Wagons........	25 to 40	
Average clay loam, free from roots, etc.	50	Drag scrapers...	15 to 20	Material such as to be loosened with plow drawn by two horses
	100	Drag scrapers...	17 to 25	
	300	Wheeled scrapers	23 to 35	
	1000	Wagons........	32 to 50	
Heavy clay........	50	Drag scrapers...	18 to 25	Four horses required for plowing
	100	Drag scrapers...	21 to 30	
	300	Wheeled scrapers	28 to 38	
	1000	Wagons........	40 to 55	
Hardpan or loose rock	300	Wagons........	40 to 65	Low prices only where material may be loosened with four horses and hard-pan plow. High prices where blasting is necessary
	1000	Wagons........	45 to 75	
Solid rock..........	300	Wagons.........	\$.65 to \$1.50	High prices apply where stone is hard and excavation shallow
	1000	Wagons.........	.75 to 1.75	

Note: Assumed conditions: All material to be loosened with plows or by blasting, and to be moderately dry when handled; hauling to be done by means of drag scrapers, wheeled scrapers, or wagons.

Table VI.—Cost of Grading and Excavating per Cubic Yard with Various Equipment Used in Road Construction in West Virginia (63a)

Distances Hauled, Feet	Wheel-Barrow	Drag or Slide Scraper	One-Wheel Scraper	Two-Wheel Scraper	One-Horse Cart	Wagon	Tractor and Trucks
100............	\$0.057	\$0.090	\$0.100	\$0.100	\$0.056	\$0.095	\$0.080
200............	0.114	0.135	0.130	0.125	0.068	0.103	0.080
300............	0.170	0.180	0.160	0.150	0.080	0.111	0.080
400............	0.230	0.225	0.190	0.175	0.090	0.119	0.080
500............	0.285	0.270	0.220	0.200	0.101	0.127	0.080
600............	0.342	0.315	0.250	0.225	0.112	0.135	0.080
800............	0.457	0.405	0.310	0.275	0.135	0.151	0.080
1000............	0.570	0.495	0.370	0.325	0.160	0.167	0.090
1500............	0.857	0.720	0.520	0.450	0.214	0.207	0.090
2000............	1.143	0.945	0.670	0.575	0.271	0.247	0.100
3000............	1.713	1.395	0.970	0.825	0.388	0.327	0.100
4000............	2.280	1.845	1.270	1.075	0.500	0.407	0.100
			Loading by Hand				
	0.050	0.010	0.010	0.010	0.130	0.130	
			Loading by Steam Shovel				
					0.060	0.060	

Note: Picking 5 cents. Plowing 2 cents. Steam plowing 1.5 cents per cu yd. Hauling by wagon approximately 35 cents per cu yd. Hauling by trucks and tram 14 cents per cu yd.

5. Specifications for Grading

The Philadelphia Specifications for Grading of Roadways are as follows:

"**Scope of Work.** The unit price bid for grading shall include the work of clearing, grubbing, removing and disposing of brush, trees, existing pavement and matter of whatsoever nature encountered; the removal and where necessary, the care of fences; all excavations and embankments or filling necessary to form roadway berms, side slopes and side ditches, and approaches to intersecting public highways or private entrances; the filling of slopes necessary to retain the footways; and at all intersecting highways, so much of the existing roadway or footway pavements and curbing as may be directed, shall be properly adjusted to the work under this contract as is necessary to make safe and easy approaches. No allowance will be made for any excavation or filling done outside of or below or above the lines and grades given by the District Surveyor, unless covered by an order, in writing, from the Engineer.

"**Permission to Dump and Borrow.** No excavated or other material necessary to be disposed of shall be dumped or placed within the limits of any existing or projected public highway, nor shall any excavation be made within such limits for the purpose of obtaining material for filling, except when specified or specifically permitted by the Engineer.

"**Dumping on Private Property.** The contractor shall have the privilege of dumping clean ashes or earth on private properties which have been declared nuisances by the Bureau of Health, but only, however, when a specific permit is issued by that Bureau. A list and map showing some of these locations is on file in the office of the Engineer, and additional locations will be added as they become available.

"**Clearing.** The ground shall be cleared of all trees, brush, stumps, roots, fences, walls, buildings and other encumbrances, upon or within the limits of the highway to be graded. The Contractor shall burn or otherwise dispose of all trees and brush to the satisfaction of the Engineer, and shall before commencing the grading, remove all rubbish or refuse from the line of the work.

"**Excess Material.** All excavated material not required or allowed in the embankment or filling shall be removed from within the lines of the highway and deposited at such locations as are specified in the proposal, or, if no such locations are specified, the Contractor shall find suitable dumping places for all such material.

"**Embankments and Filling.** All embankments and filling shall be formed of good earth, sand, gravel, clean ashes or other approved materials. Stumps, trees, rubbish, muck, tin cans, garbage and other material which, in the opinion of the Engineer, may be deemed unsuitable will not be permitted in the embankments or filling. If ashes are used in fills the top and slopes shall be covered with at least 2 ft of clean earth or gravel. When fillings or embankments are made in winter, the snow and ice or frozen earth shall not be placed in the embankments or allowed to be covered in them.

"**Rolling.** When it is specifically stipulated in the proposal, embankments shall be built in horizontal layers or courses of not more than 1 ft in thickness, for the full width of cross-section of embankment of filling, and the same shall be rolled with a 10-ton steam roller until thoroly compacted. On hillside work, where the bottom of the work does not have sufficient width for the maneuvering of a 10-ton roller, hand ramming shall be employed. All soft and unstable areas which may develop during the rolling shall be excavated and refilled with stone or other approved material, and shall be thoroly compacted by rolling or ramming. The proper cross-section and grade shall be preserved while the rolling is in progress, so that when the final rolling is completed the grading shall have a hard and firm surface true to the certified lines and grades.

"**Borrow.** When it is necessary to borrow material to complete embankments of fillings, the Contractor shall, unless otherwise specified, make his own arrangements for obtaining such materials, and when material is secured from outside the limits of the highway, the Contractor shall procure the same at his own expense.

"**Drainage.** Wherever water collects or is encountered, the Contractor shall provide ample equipment and shall pump, bail or open necessary ditches to drain the same in a manner satisfactory to the Engineer, and the cost thereof shall be included in the price bid for grading.

"**Maintenance of Water Courses.** When the work herein contemplated intercepts or in any way affects any stream, ditch, drain or culvert, the Contractor shall, where

required, arrange for keeping the same permanently open, according to the plans, lines and grades given by the District Surveyor, by rebuilding, repairing, extending the same, or by building drains, culverts or other structures of approved materials, or by laying glazed vitrified clay sewer pipe of the size required, and as directed.

"**Temporary Boardwalk and Driveway.** The Contractor shall, when directed, lay a temporary boardwalk at least 24 in in width, or temporary driveways at such points as may be designated, to provide proper access to property along the line of the work.

"**Trench Excavation for Substructures.** The term trench excavation as used in these specifications is intended and meant to indicate any trench excavation and back-filling below the confirmed grade that may be ordered done to provide for the lowering or relocation of any existing substructures where their replacement is made necessary by the grading operations. The compensation for this work will be the unit price bid or as indicated in the proposal form. The actual lowering or relocation of the structure will be performed by the Bureau to which the structure belongs and not by the Contractor.

"**Water Services.** Any water service connection work made necessary by the grading operations or by the lowering or relocation of a water main will be done by the grading contractor, who will also be responsible for the maintenance of a continuous supply of water to the premises affected. The cost of lowering or relocating these water services will be included in the compensation for such trench. The excavation as is made necessary by the lowering or relocation of the water mains, which shall be paid for at the unit price bid or as indicated in the proposal."

U. S. O. P. R. Grading Specifications for Roads are as follows (50):

General Description. "Grading shall include all excavating, filling, borrowing, trimming, picking down, shaping, sloping and all other work that may be necessary in bringing the road to the required grade, alignment, and cross-section; the clearing out of waterways and old culverts; the excavation of all necessary drainage and outlet ditches; the grading of a proper connection with all intersecting highways; the grubbing up and clearing away of all trees, stumps, and boulders within the lines of the improvement; and the removal of any muck, soft clay, or spongy material which will not compact under the roller so as to make a firm, unyielding subgrade or earth road surface.

"**Clearing and Grubbing.** "All trees, stumps, and roots within the limits of the improvement shall be grubbed up so that no part of them shall be within 6 in of the surface of the ground or within 18 in of the surface of the subgrade, except that if they occur in an area to be covered by a fill more than 18 in in depth they shall be grubbed up or cut off even with the present surface of the ground.

"**Embankments** shall be formed of the good sound earth or stone and carried up full width. The material shall be deposited in layers not more than 1 ft in thickness, and each layer shall be rolled until thoroly compacted with a roller weighing not less than 10 tons. All existing slopes and surfaces of embankments shall be plowed or scarified where additional fill is to be made, in order that the old and new material may bond together. When sufficient material is not available within the right-of-way to complete the embankments, suitable borrow pits from which the contractor must obtain the necessary material will be designated by the engineer. If there is more material taken from the cuts than is required to construct the embankments, as shown on the plans, the excess material shall be used in uniformly widening the embankments or shall be deposited where the engineer may direct. Where enbankments are formed of stone, the material shall be carefully placed so that all large stones shall be well distributed and the interstices shall be completely filled with smaller stone, earth, sand, or gravel, so as to form a solid embankment.

"During the work of grading the sides of the road shall be kept lower than the center and the surface maintained in condition for adequate drainage. The grading of any portion of the road shall be complete before any surfacing material is placed on that portion, and where the plans do not call for any substantial change in the grade of any existing section of the road, the surface shall be completely scarified to a depth of 3 in or more before the subgrade is prepared.

Classification and Payment. "All excavated material will be classed as earth and rock. Note: In general it is more satisfactory to classify the materials of excavation and to invite unit-price bids rather than lump-sum bids. However if unit-price bids are invited it is important that the various quantities be accurately determined in

order that the best bid may be selected. If lump-sum bids are desired, omit the following paragraphs.

"Only rock in place which requires blasting for its removal and boulders of ½ cu yd or more in volume will be classed as rock excavation. Materials obtained from excavation and used in embankments will be paid for as excavation only, tho the contractor is required to shape and trim the embankments properly. Materials obtained from excavation and used for surfacing will be paid for only once and at the price bid for surfacing material. Quantities of materials moved in grading will be measured in excavation and the volumes determined by the average end area method, and no payment will be made for materials excavated outside the slope lines shown on the plans unless the additional excavation is ordered by the engineer.

"The contract prices for excavation shall be compensation in full for all the work which is required to be done under the heading grading except the additional allowance at the rate of 1½ cents per cu yd per 100 ft will be made for all materials of excavation necessarily hauled more than 500 ft. The centers of gravities of cuts and corresponding embankments will be used in determining the length of haul, and if the center of gravity of the cut is more than 500 ft from the center of gravity of the corresponding fill, overhaul will be allowed for the entire amount of material in the cut for the actual distance in excess of 500 ft."

The Iowa State Highway Comm. Specifications Covering Grading of Roads are as follows:

"**Alignment, Grade Lines and Cross-Section.** The center of the finished roadway shall conform in alignment to the center stakes. These stakes shall follow, as nearly as possible, the center line of the right-of-way. The grade line shown on the profiles shall denote the crown of the finished roadway at its center lines. Unless otherwise provided the cross-section to be used is the standard cross-section of the Highway Commission for the road system on which the work is located.

"**Grading.** Under this head will be included all excavation and embankments required for the formation of the earth roadway, cutting all ditches along or contiguous to the road, forming the approaches to all side roads and farm entrances, changing of stream channels, and all other excavations and embankments connected with or incident to the construction of the road. Grading will be estimated under the following heads: Solid rock excavation; loose rock excavation; earth excavation.

"SOLID ROCK excavation will include all rock in masses which cannot be removed without blasting, also all detached rock or boulders measuring not less than 1 cu yd each.

"LOOSE ROCK excavation will include all slate or other rock which can be quarried or removed without blasting, also all detached rock or boulders measuring not less than ¼ nor more than 1 cu yd each.

"EARTH excavation will include all loose stones, boulders, and other material of and description as found, which are not included in the above specifications as solid very loose rock.

"Excavation shall be made in all cases to the required alignment and cross-section. Any roots, stumps, or other timber encountered in the excavation shall be removed and burned or otherwise disposed of as directed by the engineer but shall not be placed in the embankments. All materials taken from excavations shall be deposited in the embankments unless otherwise specified or directed by the engineer. The cost of moving the same when the average length of haul does not exceed 500 ft will be considered as included in the price per cubic yard for excavation.

"**Provision for Drainage.** If it is necessary in the prosecution of the work to interrupt or obstruct the natural drainage of the surface, or the flow of artificial drains, the contractor shall provide for the same during the progress of the work in such a way that no damage shall result to either public or private interests. He shall then be held liable for all damages which may result from any neglect to provide for either natural or artificial drainage which he may have interrupted. In cuts along side hills where there is a possibility of surface water causing damage by flowing down the side slope of the cut, a ditch shall be constructed to intercept the surface water and prevent it from flowing into the cut. The contractor will be paid for this work as an extra.

"**Borrow Pits.** When sufficient material for the embankments is not obtainable within the side ditches and excavations as staked out, the contractor shall make up

the deficiency from borrow pits laid out by the engineer. Borrowing must be done from regular shaped borrow pits in order to admit of ready and accurate measurements, care being taken not to unnecessarily injure or disfigure the land. The banks must be sloped, the pits so constructed that surface water will drain out and the premises left in a condition satisfactory to the engineer. The right-of-way for borrow pits will be furnished by the county.

"**Berms.** Wherever it becomes necessary to make an excavation along the side of the road as in the construction of borrow pits, ditches, etc, a berm not less than 4 ft in width shall be left between the toe of slope of the roadway embankment and the top of the excavation bank.

"**Waste.** When the amount of cut exceeds the amount of fill the excess material shall be deposited as directed by the engineer. Such material shall preferably be used in widening the adjacent fills so as to reduce the side slopes thereon.

"**Embankments** shall be carried up in horizontal layers, each of which shall be carried out to its proper width in the cross-section of the roadway. Sod obtained in the cuts may be deposited in the embankments provided it is so placed as to be not closer than 12 in to the finished roadway or subgrade. Stones obtained from cuts shall be so distributed in the embankments as to not form pockets or cavities. All existing slopes and surfaces of embankment shall be plowed where additional fill is to be made, so that the new material will bond with the old.

"**Guard Rail.** Where the height of an embankment is over 6 ft, substantial guard rails shall be constructed along the shoulders. Such guard rail will be paid for at the price bid per lineal foot of rail. Where the height of the embankment is 6 ft or less, the side slopes shall be flattened to a slope not steeper than 3 : 1 unless otherwise shown on the plans.

"**Sod in Blade Grader Work and Shallow Fills.** In blade grader work and in fills so shallow that the sod cannot be kept at least 12 in below the finished roadway, such sod, after being cut loose with blade grader or plows, shall be disked and harrowed until it is reduced to small pieces which will not interfere with traffic. These small pieces of sod shall not be deposited in the middle of the road but shall be deposited near the shoulders and shall be covered with earth. The middle portion of the road shall be formed of earth free from sod. The disking and harrowing of sod is included in the price bid for excavation.

"**The Side Ditches** shall be excavated to the depth, alignment, and cross-section shown on the drawings. Care shall be taken to secure a uniform grade on the ditches so that the water will readily drain out, and to secure smooth, uniform slopes on the ditch banks in strict conformance with the drawings.

"**Clearing and Grubbing.** The ground included in the highway must be cleared of trees, stumps, brush, weeds and grass to the full width of right-of-way, unless otherwise directed. All timber, stumps, brush, and other vegetable matter must be burned unless otherwise directed by the engineer. Such material shall not be placed in the embankments. Where embankments are to be more than 2½ ft in height, it will be sufficient to cut all trees, stumps, and brush close to the ground. Where embankments are to be less than 2½ ft in height, and in all excavations, all stumps and large roots must be grubbed out and burned or removed. Unless otherwise specified, clearing and grubbing will be paid for as extra work. Allowance will be made for all grubbing in excavations for the road-bed, all grubbing in borrow pits ordered and staked out by the engineer to supply material for the embankments, and all grubbing in embankments less than 2½ ft high, but will not be allowed for embankments over 2½ ft high, or in borrow pits made by the contractor without having been so ordered by the engineer.

"**Hedges,** under these specifications, are rows of trees or bushes, used for fence purposes or wind breaks, containing at least 8 bushes or trees per rod. For removing such hedges the contractor will be paid the price bid per rod.

"**Measurements.** Grading shall be estimated and paid for by the cubic yard at the prices specified in the tender. Measurements of grading quantities will, in all cases, be made from the cuts or pits from which the material is taken, by cross-sectioning before and after excavation, and the volumes determined by the average end area method.

"**Haul and Overhaul.** The average length of haul shall be determined by locating the center of gravity of the cut and the center of gravity of the corresponding fill. If

the center of gravity of the cut is more than 500 ft from the center of gravity of the corresponding fill, overhaul at the rate of 1 cent per cu yd per 100 ft will be allowed for the entire amount of material in the cut for the distance between the centers of gravity in excess of 500 ft.

"Tile Sub-Drains shall be put in wherever shown on the plans. The tile used shall meet the requirements of the standard specifications for farm drain tile adopted in 1916 by the Am. Soc. Test. Mat. (see Art. 7). The tile shall be laid true to grade and alignment established by the engineer. For furnishing and laying tile drains, the contractor will be paid at the price bid for such work. If possible, the flow line of the tile shall be placed a minimum depth of 5 ft below the elevation of the roadway shoulders. No tile less than 6 in in diameter shall be specified. Where the grade of the side ditch is less than 1%, inlets to the tile shall be provided at intervals of about 500 ft. These inlets shall be constructed by filling the trench for a length of about 8 ft with coarse gravel, broken stone, or other suitable porous material. The top of the porous material shall be raised about 8 in above the top of the trench.

"Finishing Stakes. The engineer shall set suitable finishing stakes to guide the contractor in finishing the road. Finishing stakes on fills should be set above the established grade so as to allow the proper amount of shrinkage. Under average conditions the following percentages for shrinkage should give satisfactory results:

Depth of Fill	Percentage of Shrinkage
Up to 5.0 ft	15%
5.0 to 12.0 ft	12%
12.0 to 18.0 ft	10%

"Finishing. If the road is not to be surfaced with gravel, the contractor shall, after having brought it substantially to grade, complete the work in such a manner that the finished road will be smooth and true to cross-section, grade and alignment. No extra compensation will be allowed for finishing as this work must be included in the price bid for excavation. If the road is to be surfaced with gravel, the earthwork necessary for forming the subgrade shall be executed in the manner specified for the class of gravel surfacing to be used. The preparation of the subgrade for the gravel surfacing is not included in the price bid for earth work."

DRAINAGE

6. General Considerations Relative to Drainage

All roads worth considering, except mere earth roads, consist of a subgrade, a foundation course, and a wearing course or road crust. The function of the subgrade is to carry the load of the superimposed crust and the weight of the traffic upon it. The supporting power of the soil composing the subgrade is therefore of great importance. Most soils show a great variance in bearing power in their dry and wet conditions and it is essential that at all times of the year the subgrade shall be as free as possible from water and thus yield its maximum support. Where the subgrade is of rock or sand, free from silt, clay or loam, the drainage of the subgrade is of less importance. In localities where frost conditions have to be met, the water in the subgrade expands as it freezes, thus causing the road to heave and crack and displace the road crust. Certain soils of a clayey nature, particularly the adobe frequently found in the western part of the United States, are capable of absorbing, by capillary action, an astonishing quantity of water. The swelling of the adobe and the subsequent contracting when the water dries out often cause much damage to the road crust. Provision should be made by surface drains of some character to permit all water from the roadsides and that which falls upon the road proper to run off rapidly so that as little of it as possible may

get under the road and remain there, and to take care of such water as does reach the subgrade, whether by percolation thru the road crust, by seepage from the roadsides, or from underground springs, a system of subdrains should be installed.

The Com. on "Drainage and Preparation of Subgrade" of the 1916 Nat. Conf. on Concrete Road Building, stated: "It is practically impossible to formulate specific directions for the preparation and drainage of the subgrade that will be of general application. Every piece of road construction involves problems that are complicated by local conditions, financial as well as physical, and that must be solved each by itself. The utmost that your committee can do is to consider ways and means of obtaining, as nearly as local circumstances will permit and at minimum expense, a dry foundation that will provide uniform bearing power for the pavement. It is agreed that moisture in the subgrade directly under the pavement is likely to be destructive to the surface in several ways, chiefly because of unequal vertical movements caused by frost action or unequal swelling or shrinkage of the soil due to lack of uniformity in drainage."

7. Sub-Drainage

Camber or Crown of Subgrade. The subgrade, unless the road crust is practically impervious to water falling upon it, should be crowned and its surface should be substantially parallel to the finished surface of the road. This practice not only results in economy of road metalling but in a measure offers an opportunity for such water as percolates thru the broken stone or gravel crust to run off to the roadsides. For a broken stone or gravel road the crown is usually at the rate of from ½ to 1 in to the ft of half width of roadway.

Side Ditches. In open country the simplest means of taking care of both the surface and the sub-drainage is by the construction of side ditches. The bottom of such ditches should be always established at a true grade so that the water will not collect and pond. Deep side ditches are unsightly, may cause accidents to travelers, introduce difficult problems at entering roads and driveways and are usually not possible in a much settled locality. In a flat country it is often difficult to secure sufficient fall of the side ditch and the water ponds and saturates the soil under the road proper. In such cases, instead of the ditch, it is better to install a pipe drain of sufficient capacity with catch basins or drop inlets.

Side Drains. On side hills and in cuts the underground water may be removed by the construction of side drains. A trench is dug to a depth of about 3½ ft with a bottom width of 12 in and 15 in wide at the top. The bottom of the trench must be on a true grade with a proper fall to an outlet, the fall being as great as the conditions permit but not less than 3 in to 100 ft. The bottom of the trench is filled to a depth of from 2 to 3 in with broken stone or gravel varying in size from particles passing a 1¼-in screen to those retained on a ½-in screen. On this layer of broken stone a drain tile, which should never be less than 4 in and may be as large as 6 in in diameter, is placed with the joints wrapped with cloth or oakum but not otherwise sealed. The bell end of the pipe, if bell and spigot pipe is used, should be toward the rising grade. Broken stone or clean gravel of the same size as that placed at the bottom of the trench is put around the pipe and over it to a depth of 1 ft and carefully tamped and rammed. The trench is then filled to the top with broken stone or gravel varying in size from 2½ to 1¼ in. On side hills one such drain on the up-hill shoulder of the road will usually be sufficient but in cuts it is customary to place one on each side of the roadway. Such drains may also be used to cut off springs under the roadway. Depending upon local conditions such side

drains will cost from 45 to 55 cents per lin ft including the cost of trenching and all materials.

"**Determination of Size of Pipe (8a).** The requisite size of pipe depends upon the amount of water to be carried and the grade to which the pipe is laid. There are several formulas by means of which the size can be determined. The assumptions that must be made in applying a formula to any particular case, are such as to render an accurate determination of the proper size impossible. For instance, the amount of water to be carried off cannot be more than roughly approximated, and very little reliable data relative to the flow of water in pipes of this kind are obtainable. The amount of water is generally assumed to vary between ¼ and 1 in per acre per 24 hr on the area to be drained, an average value being ½ in. Experience as to what a tile drain has accomplished in any particular locality is a better guide than any result that may be obtained by formula. It has been well established in practice that the minimum size should be 4 or 5 in. In places where no drains have been laid, the size of pipe obtained by formulas may serve as a guide in judging of the proper size to be used. The following formula is given by Professor I. O. Baker: $A = 1.9\sqrt{\frac{fd^5}{L}}$, in which A is the number of acres for which a tile having a diameter of d inches and a fall of f feet in a length of L feet will remove 1 in of water in 24 hr."

Penn. State Highway Dept. Rules for Determining Number of Drains (53). "The character of the soil and the depths of the drains will determine the distance apart at which these drains should be placed. No set rule can be given, but the following table will serve as a suggestion for the approximate spacing of underdrains. It will generally be found that one line of pipe under one side ditch placed 3 or 4 ft below the surface will give sufficient drainage, but it may be necessary to lay a line of tile under each side ditch. If one line of tile is enough, it should be placed on the side which needs drainage the most, and if the ground is sloping the tile should be placed on the higher side to intercept the water as it flows down the hill under the surface.

Table VII.—Showing Approximate Spacing of Drains for a Given Depth

Nature of Soil	Depth of Drain in Inches	Approximate Spacing of Underdrains in Feet	Remarks
Sandy or gravelly soil, loose soil	18 21 24 27 30 36 48	30 35 40 45 50 60 80	Can be used in connection with diagonal, herringbone or V-shaped systems
Clay or other plastic soils, dense soil	18 21 24 27 30 36 48	15 18 20 23 25 30 40	Can be used in connection with diagonal, herringbone or V-shaped systems

"If the water seems to originate in or near the center of the road, it may be advisable to place the drains in a manner commonly known as the herringbone system or in a V-shaped manner. The drains start in the middle and drain to the side. One advantage in this method is that the water is carried for a distance of only half the roadway and therefore requires a smaller drain and perhaps reduces the cost somewhat. In the herringbone system the drains alternate with each other, while in the V-shaped system the drains start at a common point."

Penn. State Highway Dept. Instructions for Placing Drain (53). "Whatever type of drain is used, the following points should be observed: (1) The drain should be deep enough to properly drain the road, usually 18 in to 4 ft will suffice; (2) the drain should be laid on a true grade to prevent the accumulation of silt; (3) the drains should not be laid on a less grade than 3 in to 100 ft nor more than 1 in in 5 ft, but if compelled to lay the tile on a smaller grade than above given, it would be well to lay the tile on a board 3 to 6 in wide to obtain a more even grade; (4) the drains should be covered to within about 1 ft of the surface with coarse gravel or broken stone; (5) the drains should have a good unobstructed outlet and the end should be protected with masonry; (6) it is best to substitute at the exposed end of the drain a few sections of vitrified pipe as the porous tile, if exposed, soon becomes destroyed by the elements."

Pipe Drains in Heavy Clay Cut. Bennett (16) states that "in Connecticut on what is known as Branford Hill, a heavy cut varying from 6 to 12 ft was made thru a clay soil consisting of laminated clay, that is clay deposited in layers of practically uniform thickness separated by fine sand joints. The material in this particular cut was so hard in dry weather that it was difficult for men to remove it with picks and it resisted the action of a steam shovel materially. During heavy summer rains, the material became saturated and muddy and the road leading to the steam shovel was corduroyed with old ties. Under the action of the heavily loaded clay wagons, these ties were forced into the wet clay subsoil for a depth of 2 to 3 ft. It was evident, therefore, that some radical and finished means of providing subsurface drainage was necessary to prevent any breaking up of the road surface under these abnormal conditions and the following method was employed: Two side ditches were excavated at the foot of slopes in the cut to a depth of 3 ft below the finished road grade. On the down-hill side a 6-in tile was placed in the bottom of this ditch, and on the up-hill side, a tile sufficient to take, not only the subsurface water but also the surface water which fell on the surrounding country and which was led down the slopes into frequent catch basins. The trenches about and above these tile were filled with broken stone and cross-drains laid herringbone fashion were installed beneath the road surface at approximately 50-ft intervals. On top of this drainage system was constructed a 6-in concrete road, which was practically impervious to water. With this radical and expensive treatment, no trouble has resulted from subsurface water."

Am. Soc. Test. Mat. 1916 Specifications for Drain Tile (15) are as follows:

"**Physical Tests.** 7. The physical tests of drain tile shall include Strength Tests and Absorption Tests; and may include Freezing and Thawing Tests, when specified by the purchaser in advance, or when called for by the manufacturer or other seller as provided in Sections 34, 35, 47 and 52.

"8. Selection of Specimens of Tile. The specimens of tile shall all be selected at the factory or at the shipping destination, or at the trench, at the option of the purchaser. The selection shall be made by a competent inspector employed by the purchaser. The inspector shall divide the tile into sub-classes if lack of uniformity in any important particular warrants such division and shall select enough representative specimens of tile from each sub-class for a complete set of standard physical tests.

"9. Number and Cost of Specimens of Tile. A standard physical test shall comprise tests of 5 individual tiles. Specimens of tile may be selected by the inspector in such number as he judges necessary to determine fairly the quality of all the tile. The manufacturer or other seller shall furnish specimens of tile without separate charge up to 0.5% of the whole number of tile, and the purchaser shall pay for all in excess of that percentage at the same rate as for other tile.

"**Strength Test of Drain Tile.** 10. Specimens of Tile. The specimens of tile shall be unbroken, full-size tile.

"11. Moisture Condition of Specimens of Tile. The walls of the tile shall, at the time of testing, be as thoroly wet as will result from completely covering with hay, cloth, or similar absorbent material, and keeping wet for not less than 12 hr.

"12. Temperature Condition of Specimens of Tile. No specimen of tile shall be exposed to water or air temperatures lower than 4.4° C (40° F) from the beginning of wetting until tested. Frozen tile shall be completely thawed before the wetting begins.

"13. WEIGHING. Each specimen of tile shall be weighed on reliable scales just prior to testing, and the weights shall be reported.

"14. APPLICATION OF LOAD. Any machine or hand method which will apply the load continuously, or in increments not exceeding 5% of the estimated total breaking load, may be used in making the test. The tile shall not be allowed to stand under load longer than is required for observing and recording the loads. All solid parts of the bearing frames and bearing blocks shall be so rigid that the distribution of the load will not be affected appreciably by the deformation of any part. All bearings and the specimens of tile shall be so accurately centered as to secure a symmetrical distribution of the loading on each side of the center of the tile in every direction.

"15. CHOICE OF BEARINGS. The purchaser shall choose (1) sand bearings, (2) hydraulic bearings, or (3) three-point bearings, for use in making strength tests of drain tile. See Sections 18, 19 and 20.

"16. CALCULATION AND REPORTING OF TEST RESULTS. The test results shall be calculated and reported, in pounds per linear foot of tile, in terms of the Ordinary Supporting Strength. The ordinary supporting strength, when calculated as specified in Section 16 is approximately equal to the actual supporting strength of a tile when laid in a ditch by the 'ordinary' method. See note under Table IX. The ordinary strength shall be calculated by multiplying the test breaking loads by the following factors: For sand bearings, 1.00; for hydraulic bearings, 1.25; for three-point bearings, 1.50. The result of the strength tests shall be reported separately for each of the 5 individual specimens of tile constituting a standard test together with the average.

"17. MODULUS OF RUPTURE. The modulus of rupture may or may not be calculated and reported, at the option of the purchaser. When reported it shall be calculated by the equations: $M = 0.20\,r\,\frac{W}{12}$, or $f = \frac{6M}{t^2}$; where M represents maximum bending moment in wall in pound-inches per inch of length, r the radius of middle line of tile wall in inches, W the ordinary supporting strength, calculated as prescribed in Section 16, in pounds per linear foot of tile, f the modulus of rupture in pounds per square inch, and t the thickness of tile wall in inches. Five-eighths of the weight of the tile per linear foot for sand bearings, or three-fourths for hydraulic or three-point bearings, shall be added to W in computing the maximum bending moment M, when such addition exceeds 5% of W. The value of t used shall be the average thickness of the wall at the top of the tile or that at the bottom, selecting the lesser of the two. The coefficient of 0.20 in the equation approximates the value found by theoretical analysis and also that determined by extended tests.

"Absorption Tests of Drain Tile. 21. TEST SPECIMENS. Not less than 3 separate test specimens from each of 5 separate tiles shall be taken as a standard sample for the absorption tests. Of the 3 specimens from each tile, one shall be taken from one end, another from the opposite end, and the third shall be taken from the middle portion of the tile. Each specimen shall be of from 12 to 20 sq in in area, measured upon the exterior or convex side, and shall be as nearly square as the nature of the material will readily permit. The specimens shall be obtained by breaking the tile, and shall be apparently sound solid pieces of the wall of the tile, and shall not show cracks or fissures or shattered edges due to the shock of breaking or cutting. The specimens may be obtained from the broken pieces of the tiles used in the strength test, if the restrictions as to the size and location of the specimens can be duly observed. The specimens shall be so marked as to permit the identity of each one to be ascertained at any stage of the test.

"22. DRYING TEST SPECIMENS. Preparatory to the absorption test, all specimens shall be first weighed and then dried in a drier or oven, at a temperature of not less than 110° C (230° F) for not less than 3 hr. After removal from the drier, the specimens shall be allowed to cool to a temperature of 20° to 25° C (68° to 77° F) and reweighed. If the specimens were apparently dry when taken, and the second weight closely checks the first, the specimens shall be considered dry. If the specimens were known to be wet when taken, they shall be placed in the drier for a further drying treatment of 2 hr, and reweighed. If the third weight checks the second, the specimens shall be considered dry. In case of any doubt, the specimens must be redried for 2-hr periods until check weights are obtained.

"23. WEIGHING AND REWEIGHING. The balance used shall be sensitive to 0.5 g

when loaded with 1 kg, and weighings shall be read at least to the nearest gram. Where other than metric weights are used, the same order of accuracy must be obtained. In reweighing after immersion, the specimens shall be removed from the water, not allowed to drain for more than 1 min, the superficial water removed by towel or blotting paper, and the specimens at once put upon the balance.

"24. Immersion of Test Specimens. Specimens after weighing shall be placed in a suitable woven-wire receptacle, packed tightly enough to prevent jostling, covered with distilled water or rainwater, raised to the boiling point and boiled for 5 hr and then cooled in water to a final temperature of 10° to 15° C (50° to 59° F).

"25. Calculation and Reporting of Results. The test results shall be calculated as percentages of the initial dry weight, carried to the nearest first decimal place. The results shall be reported separately for each individual specimen, together with the mean of the 15 or more specimens comprising the standard sample, the maximum and the minimum single observations entering into the mean, and the variation between the maximum and the minimum of the 3 specimens of each tile represented in the standard sample.

"**Freezing and Thawing Tests of Drain Tile.** 26. Test Specimens. The test specimens employed in making the absorption test shall preferably be used for the freezing and thawing test. In the event that the same specimens are not available, another set selected as specified in Section 21 shall be taken.

"27. Drying Test Specimens. In the event that new specimens for the freezing and thawing test must be prepared, they shall be dried as specified in Section 22.

"28. Weighing and Reweighing. The same scales and weights as are specified in Section 23 for the absorption test or others of equivalent sensitiveness and accuracy shall be employed for the weighings required in the freezing and thawing test. The same procedure in weighings and reweighing as specified in Section 23 shall be used.

"29. Immersion of Test Specimens. In the event that new specimens for the freezing and thawing test must be prepared, they shall be immersed and boiled and cooled in water as specified in Section 24.

"30. Freezing and Thawing. When the specimens, either from the absorption test or from a specially prepared series, have been weighed after saturation with water, they shall be returned to the water, and kept immersed till the freezing test is begun. For freezing, they shall be placed with their concave faces upward in water-tight metal trays, suitably mounted in a rigid metal crate, and immersed in ice water until the specimens have attained substantially the temperature of the water after which the water shall be drawn down to a depth of ½ in in each tray. The crate shall then be lifted as a whole, without disturbing the specimens, and placed in the freezing apparatus. Freezing shall be performed in a quiet atmosphere, free from perceptible natural or artificial currents. If artificial freezing apparatus is employed, the apparatus shall have sufficient heat-absorbent capacity to enable the temperature of the freezing chamber to be brought to −10° C (+14° F) or below, within 30 min after the introduction of the specimens. The temperature in the freezing apparatus shall not fall lower than − 20° C(−4° F). The freezing shall be continued until the water in the trays is frozen solid. Exposure to freezing conditions in excess of this requirement shall be considered as without significance. At the conclusion of freezing under the specified conditions, the crate of specimens shall be withdrawn and at once immersed in water at a temperature of 85° to 100° C (185° to 212° F) in a special receptacle of proper size. Heating shall be continued so that the water will regain the required temperature as soon as practicable after the specimens are immersed. A temperature of 85° to 100° C (185° to 212° F) shall then be maintained for not less than 15 min. At the conclusion of the thawing treatment, the crate of specimens shall be cooled down rapidly in water to 10° to 15° C (50° to 59° F) and then inspected. The condition of each sample after each thawing shall be noted in the records.

"31. Methods of Determining Failure in Freezing and Thawing Tests. Failure under the freezing and thawing treatment shall be considered to be reached when: (1) The specimens show superficial disintegration or spalling with loss of weight of more than 5% of the initial dry weight; or, (2) the specimens are badly cracked in other than lamination planes; or, (3) the specimens show evident serious loss of structural strength.

"32. Physical Test Requirements. The physical test requirements for the different classes of drain shall be as given in Table VIII.

Table VIII.—Physical-Test Requirements for Different Classes of Drain Tile

	Farm Drain Tile				Standard Drain Tile				Extra-Quality Drain Tile			
					Pounds per Linear Foot	Maximum Average Absorption by Standard Boiling Test, Percent			Minimum Average Ordinary Supporting Strength, Pounds per Linear Foot	Maximum Average Absorption by Standard Boiling Test, Percent		
						Shale and Fire-Clay Tile	Surface-Clay Tile	Concrete Tile		Shale and Fire-Clay Tile	Surface-Clay Tile	Concrete Tile
4	800	11	14	12	1200	9	13	11	1600	7	11	10
6	800	11	14	12	1200	9	13	11	1600	7	11	10
8	800	11	14	12	1200	9	13	11	1600	7	11	10
10	800	11	14	12	1200	9	13	11	1600	7	11	10
12	800	11	14	12	1200	9	13	11	1600	7	11	10
14	900	11	14	12	1200	9	13	11	1600	7	11	10
16	1000	11	14	12	1300	9	13	11	1600	7	11	10
18					1400	9	13	11	1800	7	11	10
20					1500	9	13	11	2000	7	11	10
22	(Not Permitted)	(Not Permitted)	(Not Permitted)	(Not Permitted)	1600	9	13	11	2200	7	11	10
24					1700	9	13	11	2400	7	11	10
26					1800	9	13	11	2600	7	11	10
28					1900	9	13	11	2800	7	11	10
30					2000	9	13	11	3000	7	11	10
32					2100	9	13	11	3200	7	11	10
34					2200	9	13	11	3400	7	11	10
36					2300	9	13	11	3600	7	11	10
38					2400	9	13	11	3800	7	11	10
40					2500	9	13	11	4000	7	11	10
42					2600	9	13	11	4200	7	11	10

Note: When the freezing and thawing test is specified or demanded, as provided in Section 7, the number of freezings and thawings to be endured shall be as follows: For farm drain tile, 8; for standard drain tile, 12; for extra-quality drain tile, 16.

"33. Absorption Requirements for Drain Tile Made of Mixed Clays. Drain tile made of mixtures of surface clays with other clays shall conform to the absorption requirements for surface-clay tile in Table VIII, when the proportion of surface clay is 75% or more, and to the requirements for shale and fire-clay tile for all other proportions.

"34. Appeal from Absorption Test to Freezing and Thawing Test. In the event that a standard sample (Section 21) of tile fails to meet the requirements of the absorption test the manufacturer or other seller may demand recourse to the freezing and thawing test, to be made at his expense. In such recourse, the number of tiles tested shall be four times the number represented by the standard sample (Section 21). If the material passes the freezing and thawing test satisfactorily, it shall not be rejected on account of its failure to meet the absorption requirements

specified in Table VIII, but the average percentage of absorption of the specimens used in the freezing and thawing test shall be adopted as the maximum allowable mean absorption for the contract in question.

"35. Limits of Fluctuation of Individual Test Specimens in Physical Tests; Culling and Retesting when Limits are Exceeded. In the strength tests, individual tiles of a standard test whose mean strength is satisfactory may fall 25% below the requirement for the average without causing rejection. In the absorption tests, the absorption of individual tiles of a standard sample (Section 21), which gives a satisfactory mean absorption percentage, may exceed the average by 25% without causing rejection. In the freezing and thawing test, at least 95% of all the tiles tested shall meet the requirement. In the event of the failure of a standard sample (Sections 9, 21 and 26) to meet the above requirements, the manufacturer or other seller may thoroly cull the material and submit a portion to retest at his own expense, and for such retest the number of tiles per sample shall be 10 for the strength and absorption tests and 20 for the freezing and thawing test. In the event of the failure of the material after culling to pass the requirements, it shall be rejected without further test.

"36. Strength Test Requirements when Manufacturer is Held Responsible for Cracking in Ditches. The manufacturer or other seller shall not be held responsible for cracking of drain tile in ditches unless by special agreement in advance, and in any event his obligation shall be held to be discharged by the delivery of drain tile having the minimum ordinary supporting strengths specified in Table IX; and, if it is not otherwise specified in advance by the purchaser, tile shall be supplied of the strengths specified for clay ditch filling, for ordinary pipe laying and for widths of ditch at the level of the top of the tile equal to 0.5 ft greater than the outside diameters of the tile. The purchaser shall furnish to the manufacturer or other seller complete information, in advance of receiving bids, as to the number of linear feet of drain tile of each diameter required for each different depth of ditch, measured to the nearest foot from the surface of the ground to the top of the tile.

Note: Ordinary Pipe Laying is pipe laying in accordance with customary good practice in tile-drain construction, whereby the underside of the pipe is well bedded on soil for 60° to 90° of the circumference.

First-Class Pipe Laying is pipe laying in accordance with the best customary practice in pipe-sewer construction, whereby the entire underside of the pipe is very thoroly bedded on soil and the entire pipe is surrounded by well-compacted soil, under the direction of an inspector constantly present on the work.

When pipe is laid in a concrete or other permanent masonry cradle, strong enough to carry the entire load to the sub-base without breaking and large enough to prevent material settlement, the standard strengths for all dimensions of ditches and all filling materials shall be those specified for Standard Drain Tile in Table IX.

"Visual Inspection. 37. Purposes. All drain tile shall be given a thoro visual inspection at the trench by a competent inspector employed by the purchaser. The purposes of the visual inspection shall be: (1) To cull and reject imperfect individual tiles; and (2) to determine whether the tiles, independently of meeting the chemical and the physical test requirements, comply with the specifications of general properties, especially as stated hereinafter.

"38. Shape. All drain tile shall be of approximately circular cross-section, except when otherwise specified in advance. They shall be approximately straight, except in the case of special connections. The ends shall be so regular and smooth as readily to admit of making close joints by turning and pressing together adjoining tile.

"39. Nominal Sizes. The sizes of drain tile shall be designated by their interior diameters.

"40. Minimum Lengths. Drain tile smaller than 12 in in diameter shall have a minimum length of 12 in. Tile of from 12 to 30 in in diameter, inclusive, shall have lengths not less than the diameters. Tile larger than 30 in in diameter shall have a minimum length of 30 in.

"41. Structure. Drain tile shall be substantially uniform in structure thruout, and the inspector shall investigate this property by examining fractured surfaces.

"42. Ring. Drain tile shall give a clear ring when stood on end and while dry tapped with a light hammer.

"43. Color. The inspector may use the color of drain tile as a general guide in

Table IX.—Standard Ordinary Supporting Strengths in Pounds per Linear Foot of Drain Tile for Ordinary Sand and for Thoroly Wet Clay Ditch Filling Materials

									Breadth of Ditch at Top of Tile											
									3 Ft				4 Ft				5 Ft			
									Method of Laying Pipe				Method of Laying Pipe				Method of Laying Pipe			
							...Class		Ordinary		1st Class		Ordinary		1st Class		Ordinary		1st Class	
							...tch ...ing ...erial		Ditch Filling Material		Ditch Filling Material		Ditch Filling Material		Ditch Filling Material		Ditch Filling Material		Ditch Filling Material	
	Sand	Clay	Sand	Clay	Sand	Clay	Sand	Clay	Sand	Clay	Sand	Clay	Sand	Clay	Sand	Clay	Sand	Clay	Sand	Clay
2	285	280	220	235	615	635	510	580	970	990	810	830	1 330	1 350	1 110	1 180	1 690	1 710	1 410	1 430
4	400	450	335	375	1 050	1 120	880	935	1 750	1 820	1 460	1 520	2 450	2 540	2 040	2 110	3 160	3 250	2 640	2 710
6	470	545	390	455	1 370	1 500	1 140	1 250	2 370	2 590	1 980	2 110	3 410	3 580	2 840	2 980	4 460	4 640	3 720	3 870
8	505	605	420	505	1 600	1 790	1 380	1 490	2 870	3 110	2 390	2 690	4 220	4 490	3 510	3 740	5 590	5 890	4 660	4 910
10	525	640	440	525	1 760	2 010	1 470	1 680	3 270	3 610	2 730	3 010	4 900	5 290	4 080	4 410	6 590	7 020	5 490	5 850
12	535	660	445	550	1 880	2 190	1 570	1 820	3 600	4 080	3 000	3 355	5 480	6 000	4 570	5 000	7 460	8 030	6 220	6 690
14	540	675	450	560	1 960	2 320	1 640	1 930	3 850	4 280	3 210	3 650	5 980	6 620	4 980	5 520	8 230	8 950	6 850	7 460
16	545	680	455	565	2 030	2 420	1 690	2 020	4 060	4 670	3 390	3 890	6 400	7 160	5 330	5 970	8 890	9 770	7 410	8 150
18	545	685	455	570	2 070	2 500	1 720	2 090	4 230	4 920	3 530	4 100	6 750	7 630	5 630	6 860	9 480	10 520	7 900	8 770
20	545	690	455	575	2 100	2 560	1 750	2 140	4 370	5 130	3 640	4 280	7 050	8 060	5 880	6 720	9 990	11 200	8 330	9 330
22	545	690	455	575	2 120	2 610	1 770	2 180	4 470	5 310	3 730	4 420	7 310	8 490	6 090	7 020	10 400	11 800	8 700	9 680
24	545	690	455	575	2 140	2 650	1 780	2 210	4 560	5 450	3 800	4 540	7 520	8 750	6 270	7 290	10 800	12 300	9 030	10 300
26	545	690	455	575	2 150	2 670	1 790	2 230	4 630	5 580	3 850	4 640	7 700	9 030	6 420	7 580	11 200	12 800	9 320	10 700
28	545	690	455	575	2 160	2 700	1 800	2 250	4 680	5 680	3 900	4 740	7 860	9 280	6 550	7 740	11 500	13 300	9 570	11 100
30	545	690	455	575	2 170	2 710	1 810	2 260	4 730	5 770	3 940	4 810	7 990	9 500	6 660	7 920	11 800	13 700	9 800	11 400
Very great....	545	690	455	575	2 180	2 770	1 820	2 310	4 910	6 230	4 090	5 190	8 730	11 100	7 270	9 230	13 600	17 300	11 400	14 400

sorting and inspecting, but he shall first so familiarize himself with the raw materials and the processes used in the manufacture of the particular tile in question as to be competent to interpret the true meaning of variations in their color.

"44. INSIDE SMOOTHNESS. Drain tile shall be reasonably smooth on the inside.

"45. CRACKS, CHECKS, CHIPS AND BROKEN PIECES. Drain tile shall be free from cracks and checks extending into the body of the tile in such a manner as to decrease the strength appreci bly. Tile shall not be chipped or broken in such a manner as to decrease their strength materially or to admit earth into the drain.

"46. USE OF THE TERMS VITRIFIED AND HARD-BURNED. All drain tile shall be sufficiently vitrified or hard-burned to afford the degree of supporting strength, percentage of absorption, and resistance to freezing and thawing specified in the physical test requirements prescribed in Table VIII.

"47. APPEAL FROM RESULTS OF VISUAL INSPECTION. The manufacturer or other seller may appeal from decisions of the inspector on questions of strength or structure when such decisions are based on visual inspection alone, in which case the point at issue shall be determined by standard physical tests, the cost of which shall be paid by the appellant, if the inspector was right, or by the purchaser if his inspector was in error.

"48. ADDITIONAL DISTINCTIVE PHYSICAL CHARACTERISTICS. Drain tile of the different classes shall, in addition to all requirements heretofore specified, have the distinctive physical characteristic prescribed in Table X."

Table X.—Distinctive General Physical Properties of Different Classes of Drain Tile

Physical Properties Specified	Farm Drain Tile	Standard Drain Tile	Extra-Quality Drain Tile
Allowable variation of average diameter below specified diameter, percent	5	3	3
Allowable variation between maximum and minimum diameters of same tile, or average diameters of adjoining tile, percentage of thickness of wall	85	75	65
Allowable variation from straightness, percentage of length	5	3	3
Allowable thickness of exterior blisters, lumps and flakes which do not weaken tile and are few in number, percentage of thickness of wall	25	20	15
Allowable diameters of above blisters, lumps and flakes, percentage of internal diameter	20	15	10
General inspection	Careful	Rigid	Very rigid

Columbus, Ohio, Specifications for Drain Pipe and Vitrified Pipe are as follows:

"**Drain Pipe.** Each tile shall be of cylindrical section, the size being designated by the interior diameter. The average diameter shall not be more than 3% less than the specified diameter. The maximum and minimum diameters of the same tile or average diameters of adjoining tile shall not differ more than 80% of the thickness of the wall. The minimum length of tile shall not be less than 12 in. In tile 12 in or over in diameter, up to 30 in in diameter, the length shall not be less than the diameter. Tile over 30 in in diameter need not have a greater length than 30 in. Tile designated to be straight shall not vary from a straight line more than 3% of its length. Tile shall be reasonably smooth on the inside, and free from cracks and checks extending into the body of the tile in such manner as to appreciably decrease the strength. Tile stood on end and tapped with a light hammer when dry shall give a clear ring. Tile shall be free from chips or broken pieces which will decrease its strength or admit earth into the drain. The end shall be regular and smooth and admit of the making of a close joint when properly turned and pressed together.

"**Vitrified Pipe.** The pipe shall be of the best quality of vitrified stone-ware hub

and spigot pipes, thoroly burned true in form, and free from cracks, warps, imperfections of any kind and shall be well and smoothly salt glazed in the best manner on the entire inner and outer surfaces. No pipe shall vary in any two interior diameters more than 2% of its nominal diameter. No pipe shall vary more than ¼ in in 2 ft from perfect straightness. When required, curved or other form of pipe shall be furnished and laid."

Blind Drains. Blind drains are essentially like the side drains already described but with the drain tile omitted. They are cheaper in cost because of the omission of the tile but they are more likely to clog up with silt and thus become ineffective. Stones of larger dimensions are employed than for the side drains and cobbles from 3 to 8 in in size are placed at the bottom graded to 1¼-in stones at the top. Drains are also constructed by making a rough box of slabs of stone at the bottom of a trench such as is described above, leaving a clear opening at the bottom of 6 by 9 in or greater, but the labor of placing the slabs will usually cost more than the drain tile.

Springs Drained by Blind Drains. Thomas (59) states that "in many cases it becomes necessary to provide in places where there are wet-weather springs or small seepages beneath the road-bed some form of drainage to carry this water off. This may be done by cutting a ditch running longitudinally and in the center of the road for the length that this water appears therein, and side ditches emanating from this to the shoulder at an angle of about 45° with the center line of the road, and placing therein large stones that can be handled by men, and then building the road surface over this. This is a very good way in which this can be done with comparatively low cost and will effect a great saving in the road making."

The V-Drain. The most effective method of providing for the sub-drainage of a road yet devised is the so-called V-drain, Fig. 6, first adopted by the Mass. Highway Comm. A trench, at least as wide as the road crust or pavement, is excavated for a depth of from 12 to 18 in in the center and to a depth of from 4 to 8 in on the sides, shaped on the bottom like a flattened letter V. This trench is filled with cobbles or rough stones varying in size from the smallest obtainable to those 8 or 10 in in diameter, the largest stones being placed at the bottom. The stones need not be placed with special care but so as to permit of their consolidation by a roller. The bottom of the trench should be tolerably true to grade, and cut-off lateral trenches filled with stones should be constructed to carry the water which accumulates at the bottom of the V-trench to outlets. Such a drain costs less usually than two side or blind drains and has the added advantage of making an excellent foundation for the road crust or pavement even over very doubtful soils (see Art. 17).

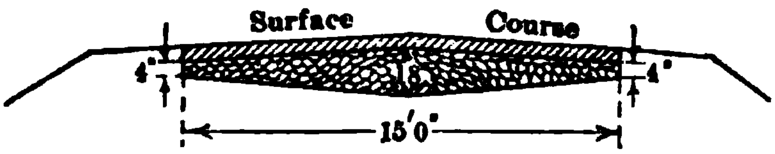

Fig. 6. V-Drain

8. Surface Drainage

Minimum Grade. The center profile of a roadway should not be level and slight artificial grades are often introduced to assist the run-off of surface water. A minimum grade of 3 in in 100 ft, 0.25%, is good practice.

Camber or Crown. The camber or crown of all roadways should be as low as will permit water falling on the surface to reach the roadsides quickly. Hard surfaced roads require a lesser crown than do those having road crusts of earth or gravel. For cement-concrete or bituminous surfaces the camber may be as low as ¼ in to the ft of half-width of roadway while earth surfaces are maintained more easily if the camber is from ¾ to 1 in to the ft. A greater crown than 1 in to the ft is rarely advisable because of the difficulty in driving at such an inclination, to overcome which the

vehicles usually straddle the center of the roadway, thus concentrating the wear. On a low-crowned roadway the traffic and the consequent wear are better distributed.

Conclusions on Crowns in 1917 Rep. Spec. Com. Mat. Road Cons. Am. Soc. C. E. (14b). "As related to drainage, the matter of the crown of the roadway is particularly important. The ideal roadway surface would be flat in cross-section were it not for the necessity of the automatic removal of surface water to the channels where it must be most conveniently carried along. Crowning the roadway tends to concentrate the traffic on the ridge where it is then most comfortable for the travelers, and the amount of crown which will result in this concentration on the ridge varies with the type of pavements. Also, the rate of crown necessary for the proper removal of storm-water to the gutters or ditches varies with the type, and with the provisions to be made for the cleaning and the upkeep of the roadway surface. In the general practice, the amount of crown for the shoulders of an uncurbed roadway has usually been a cross-slope of 1 in per ft, the shoulders being of the natural earthy material, and this rate is to be recommended for shoulders, except in special cases. The crown generally used in the construction of broken stone roadways is excessive when bituminous materials are used, and a crown of even ½ in per ft should be avoided when a lesser crown can be secured without detriment to the surface drainage. For the various roadway surfacings, the practice generally observed and to be recommended is as given in the following table:

Kind of Roadway	Crown Recommended	
	Maximum	Minimum
Gravel	1 in to the ft	½ in to the ft
Broken stone	¾ in to the ft	½ in to the ft
Bituminous surface	½ in to the ft	¼ in to the ft
Bituminous macadam	½ in to the ft	¼ in to the ft
Bituminous concrete	½ in to the ft	¼ in to the ft
Sheet-asphalt	¼ in to the ft	⅛ in to the ft
Cement-concrete	⅜ in to the ft	¼ in to the ft
Brick	⅜ in to the ft	⅛ in to the ft
Stone block	½ in to the ft	¼ in to the ft
Wood block	¼ in to the ft	⅛ in to the ft

"Concave pavements of cement-concrete, vitrified block, or stone block may frequently be found advantageous for alleys, and, in such cases, the same rates of slopes in cross-section as those previously given should govern."

Side Ditches. See Art. 2. When it is possible, the side ditches should not be deep and in cuts it is well to merely carry the camber of the roadway to the bank, thus making a gutter rather than a ditch at the roadsides. Such a form of construction is not so dangerous to travelers and the gutter

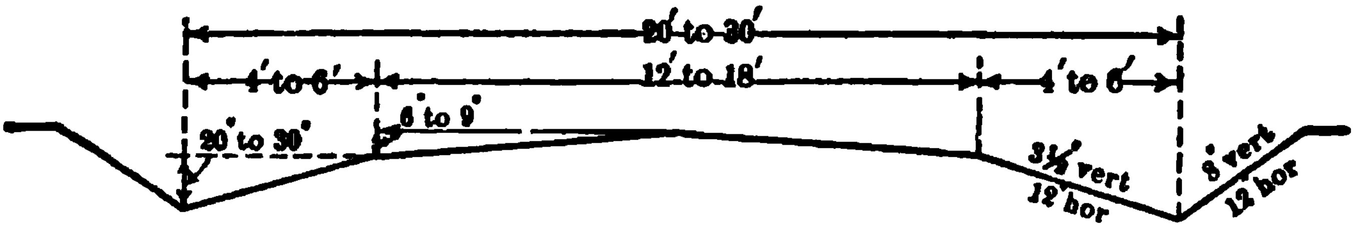

Fig. 7. V-Shaped Ditch

may be cleaned of deposits by a road machine, a difficult process if the side ditch be deep and narrow. The gutters or ditches should have outlets as frequently as the topographical features will permit so that the water may not accumulate and gully or scour the roadsides. The bottom of the

ditch or gutter should be at a true grade to prevent ponding of the water. Typical sections of ditches are shown in Figs. 7, 8, and 9. Of these the least desirable is the ditch with the trapezoidal section. Such a section is rarely necessary and it should be installed only when the volume of water is great and it is not possible to turn it from the ditch to the fields quickly.

"**Side Ditches When Road is on a Fill (53).** It is often thought that side ditches are required only when the road is in cut, that is when the roadway is below the ground at the sides of the road. It will be found that in some locations, even if the road

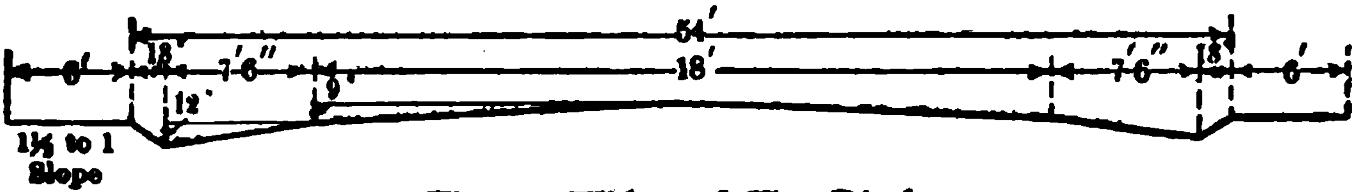

Fig. 8. Wide and Flat Ditch

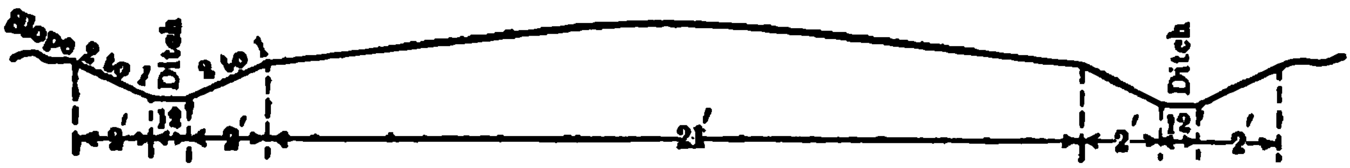

Fig. 9. Ditch with Trapezoidal Section

grade has been made by filling above the surrounding land that a ditch on either side, when the ground slopes toward the road, will benefit the road very materially. These ditches will prevent the water from seeking an outlet under the fill of the roadway and will help to keep it in a dry condition."

Slope Ditches. In cuts and on side hills it is good practice to excavate ditches on top of the banks and away from the edges to cut off water which would otherwise flow down the slopes and scour them. The side slopes are thus protected in a measure, and the gutters are relieved of a portion of their duty.

Penn. State Highway Dept. Instructions for Construction of Secondary Ditches (53). "When the road is located on a hillside it may be found that there is so much water flowing into the ditches that those of ordinary size will not hold it. In cases of this kind a secondary ditch well up on the side of the hill should be dug. It will intercept most of the water before it reaches the side ditches and save a great deal of expense in keeping up the side slope. This drain should be of sufficient depth and width to properly dispose of the water and should lead to the nearest cross-drain or away from the road if possible. These ditches, on account of their location, very quickly become filled up with debris and earth falling in from its sides and require frequent cleaning, but this expense is justified."

Paved Gutters. On gradients steeper than about 3%, where the soil scours or gullies easily, it is usually necessary to pave the gutters. The paving may consist of cobbles carefully placed and rammed, of paving blocks, paving brick, or cement-concrete. Cobble stones are used generally in the rural districts since they are ordinarily readily obtainable and cheap.

Mass. Specifications for Cobble Stone Gutters. The following specifications used in the Massachusetts State highway work represent the best practice.

"No gutter is to be laid until after the broken stone has been rolled, unless otherwise ordered by the engineer. In no case is the roller to pass over any part of any paved gutter.

"**Dimensions.** Gutters not exceeding 400 ft in length shall be 3 ft wide with a shoulder 1 ft wide and a dish of 3 in. Gutters exceeding 400 ft in length shall increase the dish above this length at the rate of 1 in to each 300 ft.

"**All Stone** used in gutters shall be rounded field, bank, or river stone; no flat, shaky, or rotten stone shall be used. The stone may, on the average, lay from 4 to 6 sq yd to the ton. A cubic yard may be estimated to weigh 1½ tons. The larger selected

stone will be laid in the gutter row and on the edges to a true line and grade, with the largest diameters lengthwise of the road. All other stone will be laid with the longest diameters across the gutter.

"**Construction.** The trench shall be excavated to a depth of 12 in below the finished grade of the gutter; gravel shall then be spread and rammed to a depth of 4 in. A layer of bedding sand, or gravel free from stone larger than ½ in in diameter, shall then be spread of a sufficient thickness to bring the gutter stone which are bedded in it to the proper grade and cross-section after they are thoroly rammed. Each stone is to be rammed to an unyielding foundation. The contractor shall employ one rammer to every two pavers. The surface shall then be covered with coarse sand or fine screened gravel free from clay or dirt, which must be well broomed into all joints. The stone shall then be rerammed and the surface left smooth and even. If from any cause the stone in a gutter shall have been disturbed and left uneven, they must be relaid by the contractor and at his cost. Sand or screened gravel shall then be spread over the entire surface of sufficient depth to fill all interstices. The edge of the gutter toward the road shall be left ¼ in below the surface of the adjoining broken stone; in no case must it project above it. All broken stone which may be disturbed during the paving of the gutter must be carefully replaced and thoroly rammed. The bank on the outside of the gutter must be sloped to the gutter, so as to have no bunches or depressions on its surface."

The specifications for stone block, brick and cement-concrete pavements given in Sects. 19, 20 and 21 respectively, may be used for the other types of paved gutters. Also see Sect. 25, Arts. 12, 13 and 14.

Oiled Gutters. It is sometimes advisable, when a better type of gutter is not possible because of the lack of suitable materials at a reasonable cost, to apply asphaltic oil to the shoulders of the road and to the gutters. The oil combines with the soil to some extent and tends to greatly lessen the scour. This type of work is but a temporary palliative but it may often be employed for a season or two until paving can be installed.

Culverts. At low points in the grade, at stream crossings and whenever it is necessary to deflect the surface water from one side of the highway to the other, suitable culverts must be installed. The required area of the waterway of every culvert must be figured to ensure that it is of sufficient capacity to carry quickly the water which comes to it. Culverts may consist of concrete pipe, vitrified clay pipe, cast iron or corrugated iron pipe, stone masonry or concrete. Formulas for run-off and specifications for construction of these several types of construction will be found in Sect. 26, Arts. 12 and 13.

On mountain grades and on side hills, it is frequently advisable to install pipes from the gutter on the uphill side at very frequent intervals. It is difficult to overdo this precaution, and on grades in excess of 5% a 12-in pipe every 300 ft is almost the minimum. Where the water from such a pipe discharges upon the slope of an embankment, it is frequently necessary to pave the outlet to prevent scour and it is good practice to install headwalls of stone masonry or concrete at the lower end of such pipes.

9. Catch Basins and Inlets

Catch Basins and Drop Inlets. The upper ends of culverts installed to carry water under the roadway usually require catch basins or drop inlets to impound the water. They may be built of either brick or concrete. Several types of such structures are given in Figs. 10 to 15 inc. The bottom of the catch basin is usually placed 1 or 2 ft below the bottom of the pipe so as to provide a sump to hold back dirt and debris from entering the culvert pipe. This practice is not always necessary if the culvert pipe is laid on a considerable grade. Such pipes should always be inclined as much as the topography will permit to facilitate the speedy flow of the

water. The outlet pipes of catch basins in cities often connect with sewers, carrying house sewage, and hence it is essential, in such cases, that the

Fig. 10. Pittsburgh Catch Basin with Brick Walls

Fig. 11. Pittsburgh Catch Basin with Concrete Walls

pipes be trapped in order to prevent the emanation of objectionable gases from the sewers. Drop inlets should be installed as far from the traveled way as possible so as to be out of the way of travel. If of necessity they have to be placed in the line of the gutter, suitable iron gratings must be provided, of sufficient strength to sustain any load likely to pass over them and of such design that the water will pass thru the openings freely while sticks and large debris are held back.

Fig. 12 N.Y. State Highway Dept. Concrete Catch Basin

Percolating Basins. In flat country where there appears to be no chance to drain water from the roadside except by costly pipe installation, it is sometimes

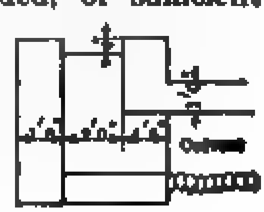

Fig. 13. Maine Highway Dept. Box Inlet

Fig. 14. Pittsburgh Box Storm Inlet

Fig. 15. Pittsburgh Pipe Storm Inlet

possible to take care of the water, in a measure, by the construction of percolating pits. Such pits may be 3 or more ft in diameter and deep enough to pass thru an impervious layer to a pervious layer. The pit so dug is filled with rough stone. This form of construction is advisable only when the impervious stratum is thin.

Inlet Castings. There are many different types of castings used as covers for catch basins and inlets. If a casting is so placed that traffic will pass over it, a very strong type will be required.

Pittsburgh Specifications for Catch Basins (see Figs. 10 and 11) are as follows:

"**Work Included.** The contractor shall furnish all labor, tools and all materials except castings, excavate for and construct brick catch basins of all classes and types required on the contract plans, in accordance with the Contract Plans, the Standards for Street and Sewer Construction and as herein specified.

"**Description of Standard Catch Basins.** The details and dimensions of each class and type of standard catch basin are contained in the Standards for Street and Sewer Construction and the catch basins shall conform thereto. Catch basins consist of a brick structure to which a terra cotta pipe connection is made, the inside bottom of the brick structure being constructed at a depth of 1 ft or more, as required on the detail plans, below the invert of the terra cotta pipe outlet. Standard storm inlets in which the bottom of the structure is approximately flush with the invert of the outlet and in which the stench plate or trap is omitted are paid for under a separate item.

"**Brick Masonry.** The brick masonry in the catch basins shall be built with ordinary sewer brick and the construction of the brick masonry and the materials therefor shall conform to the requirements of the General Specifications for Brick Masonry.

"**Excavation.** Excavation for catch basins shall, in all cases, be included in the price bid for catch basins. On repaving work the price bid shall include all excavation and the disposal of the same, together with the old paving materials. Excavation and back-filling shall be done in accordance with the requirements of the Specifications for Trench Excavation, except as herein otherwise stipulated. The face of the excavation shall be at least 6 in from the exterior surface of the masonry.

"**Back-Filling.** Back-filling shall be done with selected materials, thoroly rammed and compacted, and shall be carried up with the work and placed as soon as the mortar has sufficiently set.

"**Catch Basins Rebuilt.** Where catch basins are to be constructed to replace existing structures, in the locations shown on the Contract Plans, the Contractor shall remove the old structure and dispose of the materials, except that the castings shall remain the property of the City. When the bottom of the old catch basin is below the proper subgrade of the new structure, the Contractor shall fill the same to the required height.

"**Mortar Plaster.** The interior surfaces of the bottom and side walls up to the top of the stench plate shall receive a plaster coat of Portland cement mortar, ½ in in thickness, which shall be applied immediately after the completion of the brick work.

"**Castings.** All castings shall be furnished by the City and shall be delivered on the site of the work free of cost to the Contractor. The Contractor shall place all castings on the brick work in full beds of mortar and shall adjust the same to the established grade of the street. The catch basin covers, when required, shall be filled with concrete and finished with a mortar coating ½ in in thickness. The gravel used in this concrete shall not exceed ¾ in in the greatest dimensions. The surface of the concrete shall be finished so as to conform to the surface of adjoining sidewalks.

"**Bolts.** The Contractor shall furnish and place all bolts required for the assembling or placing of the castings.

"**Gaskets.** All catch basins provided with a cast iron trap having a removable plate require the insertion of a gasket, as shown on the detail plans. This gasket shall be furnished and placed by the Contractor.

"**Depths, Catch Basin, Type 1.** Unless otherwise required on the contract plans, the inside bottom of Type 1 catch basin shall be 6 ft 5⅝ in below curb grade. Where greater depth of basin is required, the same will be marked upon the contract plans and the catch basin shall then conform thereto.

"**Measurement and Compensation.** The price bid for catch basins shall be a lump sum price per catch basin and the unit price bid shall include building catch basins of all classes and types required on the Contract Plans. The price bid per catch basin shall include all excavation without classification of materials, back-filling, furnishing all labor, tools and materials, constructing the catch basin and doing all work as hereinbefore required in conformance with the Contract Plans, the Specifications and the Contract."

FOUNDATIONS

10. General Considerations Relative to Foundations

Necessity for Adequate Foundations. The foundation of the roadway must sustain the load which comes upon the crust or pavement. As stated already in Art. 1, the foundation, if it be of soil, must be kept as free of water as possible. All soils in a dry state will sustain greater loads than when they are wet. The crust or pavement distributes the load over the foundation and in a measure the thicker and more rigid the crust or pavement, the more the load is distributed.

Results of Investigations by the Mass. Highway Comm., made to ascertain the proper thickness for its water-bound broken stone roads, were given as follows in its 1901 Report. "Sand, gravel and porous soils give no trouble at any time; while clay, sandy loam and all non-porous soils are much weakened by frost action, and in their natural condition afford poor support in the spring months, they can, however, be greatly improved by removing from them the ground water, which in a measure may be done by means of side drains. The commission has estimated that non-porous soils, drained of ground water, at their worst, will support a load of about 4 lb per sq in; and, having in mind these figures, the thickness of the broken stone has been adjusted to the traffic. On a road built of fragments of broken stone, the downward pressure takes a line at an angle of 45° from the horizontal, and is distributed over an area equal to the square of twice the depth of the broken stone. If a division of the load, in pounds, at any one point, by the square of twice the depth of the stone, gives a quotient of four or less, then will the road foundation be safe at all seasons of the year. On sand or gravel the pressure may safely be placed at 20 lb per sq in."

The Conclusions of the Second Int. Road Cong. (3b) at Brussels in 1910 concerning foundations were as follows. "The strength of road foundations should be increased in proportion as the supporting power of the ground decreases. The foundation should have more body and resistance, the more it is exposed to internal deterioration and external wear. In the choice of the system of foundations for both stone block pavements and metalled roads, due consideration should be given to the condition of the subsoils, with regard to the possibility of their drainage, to their geological nature and to the nature of the materials of the locality. In order to determine the thickness and the extent of the foundations, the pressure per unit area should be made compatible with the carrying resistance of the soils, observed under the most unfavorable conditions."

Prevention of the Subcrust Movement in Roads. Sinnott (57) states that experiments have been initiated to determine the lateral and longitudinal movement of material forming the subcrust of highways. As a preliminary to more precise investigations various sections of grass verge adjoining the principal roads in Gloucestershire were opened. These indicate that lateral movement, in some instances to a considerable extent, has been taking place, and such movement seems to call for special consideration. The following examples will serve as illustrations: On main road, Gloucester to Bristol, at Whitfield, near Falfield. At this point the grass verges were opened on both sides of the road, and on the west side there was found, at a depth of about 4 in, a bed of broken limestone having a width of 3 ft from the metalled surface, varying in thickness from 7 in nearest the road to 4 in at the 3-ft distance. On the east side a somewhat similar state of affairs was found to exist, the width in this case being 2 ft 6 in from the verge. The subsoil was a hard, red clay. On the main road, Gloucester to Bath, between Hardwicke and Stonehouse. In this case metalling and pitching were found from 3 ft to 5 ft from the metalled surface, and about 18 in in thickness. The subsoil consists of clay and sand.

As one means of preventing the action above described, a rigid framing has been recently designed and put into use, the essential feature of which is that longitudinal and cross-members placed at a suitable depth below the surface preclude any movement of the subcrust, and at the same time provide a means of constructing an impervious arch of tar concrete to carry the traffic, great additional strength being provided by the longitudinal members for the support of the heaviest road vehicles. For various reasons the writer thought it best to construct the frames in ferro-concrete, altho timber or other material could, if preferred, be used. The longitudinals were 12 in by 3½ in by 12 ft long, and were slightly tapered from top to bottom. The ends of the longitudinals were securely housed at the extremities of the cross-ties. The reinforcement consisted of expanded metal, 3-in mesh, $^1/_4$ in by $^3/_{10}$ in, weighing $11^1/_2$ lb per sq yd, cut into strips 9 in wide. In the case of the cross-ties this is supplemented in a minor degree with wrought-iron round bars of small section at the ends of the same.

Pavement Foundations for Heavy Traffic. Goodsell (37) states that, "in order to present an idea of the stresses which may be produced by heavy vehicle units or groups of units, the accompanying Table XI, based on observed weights and tire widths, is presented for consideration. It is believed that the weights represent average conditions for trucks in the Borough of Manhattan, New York City.

Table XI.—Showing Weights per Inch Run on Tires of Four-Wheeled Trucks

Power	Number of Vehicles Avgd.	Average Tire Width per Truck in Inches	Average Load in Pounds per Inch of Tire Width	Maximum Pounds	Minimum Pounds
One horse	19	10.12	572	1263	300
Two horse	68	12.92	848	1333	429
Three horse	10	15.70	1115	1590	850
Auto	9	19.40	822 1182*	1154	643

*Rear.

Table XII.—Showing Weights of Some Heavy Trucks and Loads

Power	Load Pounds	Width of Tires in Inches			Pounds per Inch Run	Weight of Truck in Pounds
		Front	Rear	Total		
Three horse	16 000	4	4	16	1000	6 300
Three horse	20 000	4	4	16	1250	7 000
*Twenty horse	166 000	14	14	56	2964	24 000
Auto	6 000	4	8	24	250	8 000
Three horse	35 000	6	6	24	1458	8 300

*The 20-horse Reach truck is believed to be the heaviest in New York City. It is known as the whale. Its designed load of 100 tons is evenly distributed to the four solid cast-steel wheels with 14-in faces. The heaviest load so far carried was a steel girder weighing 83 tons, which was used in the Woolworth building. With a load of 100 tons, the weight per inch run of tire is 3571 lb.

"Damage to Roads, Middlesex, England (37). As to 6 in of concrete being insufficient on roads, experience bore out that opinion. On the Greenlanes, Wood Green, after 6 months' motor traffic, the wood paving was found not only to be corrugated but in blisters and depressions, and it was necessary to reconstruct the road. When the wood blocks were removed it was found that the 6-in concrete foundation underneath was so absolutely fractured that there was not 1 sq yd of sound concrete left. The whole of the material was fractured and damaged to such an extent that it not only had to be excavated but relaid 10 in in thickness for the wood blocks, which

already showed signs of breaking. Cement grouting is never used in connection with wood paving here, a bituminous filler having been found more satisfactory.

"EXPERIENCE IN WIMBLETON, ENGLAND (37). The damaging effect of this latter form of traffic, motor busses, so far as we can see at present, has resulted in the destruction of Portland cement-concrete 6 in thick, where placed beneath wood paving and asphalt.

"EXPERIENCE IN THE CITY OF WESTMINSTER, ENGLAND. The City Council last year approved an alteration in their specifications for paving work to provide for the laying of 8 in of concrete foundation and 1 in of floating, instead of 6 in of concrete and 1 in of floating formerly specified.

"KANSAS CITY, in 1913, increased the thickness of foundation on business streets and traffic ways from 6 to 8 in of 1 : 3 : 6 Portland cement and on residence streets from 5 to 6 in. No foundation is laid less than 6 in thick, and several streets have been repaved with a new foundation 8 in thick. Eight inches on residence streets and 10 or 12 on business streets should be required and will probably be specified as soon as the public will allow it."

Integral Parts of a Roadway. Earth roads and some gravel roads have no distinct foundation since the wearing course is not separable from the underlying soil, but all kinds of roadways having as wearing courses the more highly improved types of roads and pavements may be considered as made up of three parts: the subgrade or the natural foundation; a superimposed artificial foundation; and the wearing crust or pavement.

11. Natural Foundations

Except where the subgrade is of rock, the natural foundation consists of one of the many varieties of soil.

Soil Classification. The solid rocks of the earth are reduced to soil by four principal agencies: mechanical, atmospheric and aqueous; chemical, solution and precipitation; igneous, high temperature; and organic.

Residual and Alluvial Soils. Soil in place is classified as residual or sedentary. Residual soil is found at or near its original rock source and contains all of the decomposed minerals of the parent rock and more or less decayed vegetable or animal life. Soil which has been carried away from its original source is classified as alluvial or transported soil. The transporting agencies of nature cannot usually carry the soil to a new location without greatly altering its character. If carried by water, soluble minerals are removed, minerals of different specific gravities are separated by the concentration of those of like gravities and are so deposited, and in a purely mechanical way the water separates the finer particles from the coarse and the lighter and finer materials are carried further and deposited after the heavier and coarser particles. Silica being the most abundant of the rock forming minerals, and because of its insolubility and chemical stability, is usually the principal mineral found in soils; the more or less complex salts of alumina, iron, calcium, magnesia, and other more base minerals in varying amounts make up the balance of the organic soil material.

In a **Physical Classification** soils are divided into gravels, sands, silts, and clays. If their chemical composition is considered, the terms loam, peat, and marl would help in describing the classification of silts and shales.

Sands and Gravels. The dividing line between sands and gravels is made by classifying as sand the mineral aggregate passing a 10-mesh sieve or ¼-in screen, and classifying as gravel the rock fragments that are retained upon a 10-mesh sieve or ¼-in screen. The extensive gravel beds composed of rocks fairly uniform in size were generally laid down as ocean beaches during a former geologic age. The ocean is one of the most active agents for piling together rock of a like size on one beach and sand grains of a uniform size upon another beach. It is the great concentrator of clean gravel and clean sand. Torrential streams deposit fairly clean gravel and sand bars. The glacial period in America was a time when nature's rock crushers were producing their maximum output of crushed rock, sand and dust. Where the glacial deposits have been subjected to river and stream action, the gravels and sands have been freed from the finer silts and roughly separated into gravel and sand bars along the stream beds, making these deposits of greatest commercial importance. Sand being composed of smaller rock fragments than gravel presents a very much greater

surface exposure to weathering and the action of water and other solvents, and, therefore, by removal of its soluble minerals contains a much higher percentage of the chemically stable minerals, of which quartz or silica is the most common. For this reason fairly pure quartz sands are the more common of the sand deposits. Physically, sands are classified as sharp or rounded, and as fine, medium, or coarse. The sand obtained at or near the residual soil source will contain a higher percentage of the chemically unstable mineral particles than an alluvial sand which has been carried by water or other natural agencies and freed from most of the less stable mineral constituents. The river deposits of either gravel or sand, or a mixture of both, usually give a fairly uniformly graded material running from the smaller rock or grains to the coarse. The ocean deposits, as has been stated, usually supply a concentration of material, all approximately uniform in size.

Silt and Clay. Silt is very fine rock dust in which the particles, when wet, behave like sand. It differs from clay, which when wet has a semi-chemical or colloidal action with the water, causing it to become plastic, or sticky. Volcanic dust, the wind deposited silts of the desert, the silicious diatomaceous shales are of the silty nature. The clays are the silicious salts of alumina, iron, calcium and other base minerals that make a weak chemical, or a colloidal reaction with water. Clay which has been wet will shrink upon drying. The clays formed from the decomposition of the feldspars and more silicious or acid rocks show less shrinkage than those derived from the more basic rocks. Thruout the western part of the United States the ferro-magnesian lavas upon decomposition have produced clay which has a very great shrinkage upon drying; this is known as adobe.

Loam and Marl. The presence of clay and decomposed vegetable matter in soil would class this as loam. An excessive amount of decomposed vegetation would give the soil a classification of peat. Clay or shale beds carrying more than 15% of lime carbonate in the form of shells or lime are classified as marl. If the lime content exceeds 25%, the bed would be an argillaceous limestone.

For a further discussion of the classification of soils, see Sect. 3, Arts. 7, 8 and 9.

Preliminary Investigations of Natural Foundations. The soil foundation of a highway should be examined to determine what treatment will be necessary to make it suitable as a foundation for the pavement it is to support. Test pits will determine if there are new underlying soil conditions requiring special treatment. The behavior of the soil when wet as well as when dry should be considered and where the soil is one that changes materially in volume after each wet and dry season, it should receive special attention. If the roadway is to be paved with a rigid pavement then a layer of coarse mineral aggregate should be worked and rolled into the subgrade before the pavement is laid. Gravel, crushed rock, shells, slag or coarse sand can be used for this purpose. The physical examination of a soil is generally sufficient for a highway engineer working in country with which he is familiar. A rough sieve test to determine the percentage of gravel and of 30, 100 and 200-mesh material is usually sufficient to roughly classify the soil. When time will permit of a comparison of the soil in wet and in dry seasons, the field will as a rule furnish more useful information than the laboratory.

Safe Loads for Natural Foundations. The following table giving safe loads per square foot has been prepared by Professor William H. Burr, for structural work to be erected on soil foundations:

	Lb per Sq Ft
Well-drained clay, practically dry	8 000 to 12 000
Clay, moderately dry	4 000 to 8 000
Soft, moist clay	2 000 to 4 000
Coarse sand or gravel in undisturbed and well-bonded strata	12 000 to 18 000
Thoroly compacted and bonded ordinary sand, well held in place	4 000 to 8 000

Much can be determined in the field by watching the behavior of the subgrade under the action of a roller of known weight or of loaded wagons hauled over the prepared subgrade.

12. Gravel Foundations

Bennett (16) states that this type of foundation "is to be used where small stone or gravel is available for base fill and the soil is of a more or less doubtful character, and where a watertight and heavy surface is to be placed on the road, such as concrete or a heavy bituminous macadam. Again this stone or gravel fill should be supplied with frequent outlets to water-courses."

Construction of Gravel Foundations by Johnston (14). "It is true that if you can obtain the right kind of gravel it makes an excellent foundation, but to give the best results it should be absolutely free from clay, loam or silt, and rather sandy. For instance, on such a base have been built macadam roads with only 3 in of broken stone. There were a few soft spots in the spring where pockets of loamy gravel were found, but these were taken out when they developed, and one such road, which carried a considerable traffic on the edge of a flourishing village, was kept in excellent condition at low cost for maintenance for 12 years before it was resurfaced. In another place a section of road was built over a very soft bottom, practically quicksand, by first placing a bed of gravel 18 in deep, and over that 6 in of macadam. This road has been built 16 years and has given no trouble. On the other hand, many miles of road, built on gravel bases 6, 12 and in some cases 18 in deep, have softened up and rutted badly in the spring when the frost is coming out."

The N. Y. State Highway Comm. Specifications for Gravel, Broken Slag and Broken Stone Foundations are as follows:

"**Work.** Under these items the Contractor shall furnish and place stone, slag or gravel, conforming to the general requirements for same, either upon the properly prepared subgrade or upon the foundation course. This stone, slag or gravel shall be of sizes specified below.

"**Material.** After the subgrade or foundation course shall have been properly prepared and proper drainage provided, a course of broken stone, broken slag or gravel of graded uniform mixture of No. 3 and No. 4 (see note on sizes at end of specifications) shall be spread evenly so that it will have after rolling the required thickness. One inch of No. 2 stone, slag or gravel may be used in the bottom course if placed on the foundation and will be considered a part of the course. In cases where the finished thickness of the bottom course is to be more than 5 in, the broken stone, broken slag or gravel for it shall be spread, rolled and filled in two separate layers neither of which shall be of a greater depth than 6 in measured loose.

"**Gauging Block.** The depth of loose stone, slag or gravel in all cases, whether in foundation bottom or top courses, shall be gauged by the use of cubical blocks of suitable size.

"**Dumping on Roadway.** The spreading of any layer or course of broken stone, broken slag, gravel or filler, whether in foundation bottom or top courses, shall be done from suitable spreader wagons or from piles dumped along the road as directed by the Engineer. No segregation of large or fine particles will be allowed, but the stone, slag or gravel as spread shall be well graded with no pockets of fine material.

"**Rolling and Filling.** After the bottom course of stone, slag or gravel has been laid loose it shall be thoroly rolled with an approved roller weighing not less than 10 tons. This rolling must begin at the sides and continue toward the center and shall continue until there is no movement of the stone or slag ahead of the roller. After the stone or slag is thoroly compacted No. 1 stone, slag or gravel, and screenings or sand, or a mixture of these, shall be uniformly spread upon the surface and swept in with rattan or steel brooms and rolled dry. After the completion of the rolling no teaming other than that necessary for bringing material for the next course shall be allowed over the rolled material. It is the intention to bind this course with the small stone or slag but no surplus of filler will be allowed on this course. This course should not be laid in excess of 500 lin ft without being rolled and thoroly filled so as to render it waterproof and thereby prevent the softening up of the subgrade.

"**In Case of Two Courses.** When two courses of bottom stone or slag are laid each course shall be treated by rolling and adding fine material as described above.

"**Replacing.** If the subgrade material shall become churned up into or mixed with the bottom or sub-bottom courses thru the Contractor's hauling over it or working on it when the subgrade is in a wet condition, the Contractor shall at his own expense remove such mixture of subgrade material and broken stone, broken slag or gravel and replace it with clean broken stone, broken slag or gravel of the proper size, and shall roll or otherwise compact the material so as to produce a uniform, firm and even bottom course. If the above condition occurs thru no fault of the Contractor, the Contractor shall be paid both for excavating and replacing under the items excavation and bottom course respectively.

"**Piles of Filler.** All filler for top and bottom courses shall be delivered and piled alongside the road before the course in which it is to be used is placed.

"**Note:** The Sizes of All Stone, Slag, Gravel, etc, used under these specifications shall be determined by its passing over the minimum and thru the maximum apertures for the various sizes tabulated as follows:

Size of Aperture		
Retained on	Passing	
	¼-in square, or ⅝-in circular	Screenings
¼-in square, or ⅝-in circular	⅝-in circular	No. 1
⅝-in circular	1½-in circular	No. 2
1½-in circular	2¾-in circular	No. 3
2¾-in circular	3¾-in circular	No. 4

Inasmuch as the screened product will also vary because of the angle, speed and diameter of the screen, the capacity of the elevator and the quality of the material being crushed, all these factors must be so adjusted that the resulting screened product shall be so sized that not more than 15%, by laboratory test, shall pass the smaller opening mentioned."

13. Broken Slag Foundations

Blast-furnace slag as a foundation is discussed by Brown (23) as follows: "A smooth surface has been obtained by a careful selection and placing of the slag in the foundation courses. Ordinary bank slag was used with a top coat of screenings, and then rolled by a 10-ton tandem roller to a compacted thickness averaging 7 in. As the slag was brought on the street, laborers with sledges broke all large pieces, while other laborers placed the slag in a layer of proper thickness, being careful to place all large pieces in the bottom and the smaller ones on top. On this was placed a generous layer of screenings. The whole was then thoroly rolled until no visible voids remained. The slag, because of its keen edges, takes more rolling to compact it than is required for broken stone or gravel. Owing to the labor required in placing and breaking, and the cost of the screenings, this one street cost almost as much as a broken stone or gravel foundation would have cost. However, it is firmly believed that the use of granulated slag as the foundation material is the solution of a cheap and durable paved street, especially in a locality within reach of the low freight rates of the steel mills. At the present time the Contractor can obtain granulated slag for a very small cost, plus the freight, and in some cases the freight is the only cost. Granulated slag has been used for the foundation of paved streets, and it has been found that thoro rolling under a heavy roller will make a dense foundation, especially if water is used. Such foundations in use for 4 or 5 years are so well cemented that it is difficult to break thru them in repairing water and gas mains."

Specifications. See Art. 12 for N. Y. State Highway Comm. specifications.

14. Broken Stone Foundations

The lower course of a broken stone road is the foundation course (see Sect. 11). The thickness should vary with the stability of the subgrade and the intensity of the traffic. When Telford is used as a foundation, the lower course of broken stone need rarely be greater than 4 in, but when the lower course of broken stone rests directly upon the subgrade it is often advisable to lay it to a depth of 6 in, after rolling.

Broken Stone vs Cement-Concrete Foundations as presented by Warren (62e). "If the sub-soil is of the nature of clay and the climate is such that the sub-soil is liable to become wet before the waterproof pavement surface is laid, then it is unsafe to specify broken stone base because in such wet, yielding condition the sub-soil does not provide a subgrade over which either the crushed stone or the bituminous surface can be properly compressed. If, on the other hand, the sub-soil is of a gravelly nature or if in a climate where it seldom or never rains during the working season, no more serviceable nor equally low cost foundation can be produced for a stable bituminous wearing surface than a thoroly rolled crushed stone base. This has been abundantly proven in many cases, of which two will be cited. In El Paso, Texas, the sub-soil is generally caliche, a sort of clay bonded gravel, but sometimes gravel without the clay and vice versa. Here during the past 10 years, there has been laid a total of 586 000 sq yd of Bitulithic pavement on 46 streets and all of it was laid on a rolled broken stone base. In Portland, Oregon, the soil is generally clay or loamy clay, but in some cases it is gravel. Here Bitulithic pavements have been laid during the past 12 years on 250 streets to the extent of 2 278 500 sq yd. In both cities many of these pavements are on heavy traffic business streets.

"It is a well-established fact that with a dense, stable, waterproof pavement surface, rolled crushed stone base practically overcomes the cracking incident to Portland cement-concrete base. It is also self-evident that crushed stone foundation has the important economic advantage that in the case of broken stone base the bituminous wearing surface under pressure of the roller fills the chinks in the surface of the foundation and forms an important union between the foundation and the surface which is impracticable in the long run with either Portland cement-concrete or silicate of soda concrete foundations."

Portland, Oregon, Specifications for Broken Stone Foundations are as follows: "On the rolled subgrade, stone, conforming to standard specifications for Broken Stone No. 2, varying in size uniformly from 1¼ to 3 in in diameter, free from all perishable material shall be uniformly spread over the entire roadway to such a depth that, when compressed with a road roller allowing a compression of not less than 200 lb per in width of tire, the thickness shall be not less than 4 in. After completion of the rolling, a coating of asphaltic cement of the quality above specified, shall be evenly spread over the entire stone foundation to the extent of from ½ to 1 gal per sq yd of surface, to allow of a firm bond between the stone foundation and the binder course below specified. The laying of broken stone foundation more than 24 hr in advance of the binder course shall not be permitted unless upon the express authority of the Commissioner of Public Works."

For N. Y. State Highway Comm. Specifications, see Art. 12.

15. Rough Stone Foundations

In Connecticut, according to Bennett (16), rough stone base consists of a depth of from 12 to 18 in of rough stone laid on the subgrade of the road with frequent outlets to water courses and without great regard to the uniformity of the sizes of the stone themselves or the character of the material making up the stone. This method should be used in the building of roads thru clayey material, which is liable to become saturated and flow, and should be extended beyond the edge of the road surface proper.

Rhode Island Specifications for Rough Stone Foundations are as follows: "The stone to be used may be either wall stone or cobble and no stone shall be larger than 8 in in its longest dimension, nor shall it be small enough to pass thru a 2-in ring. The largest stones shall be placed in the bottom and no point of a stone larger than will pass thru a 4-in ring shall be allowed to be within 2 in of the top surface of the stone in the trench. The stone shall be free from foreign matter and no earth shall be allowed to fall into the trench after the trench is excavated. The stone in the trench shall be rolled until firm and solid with a self-propelled roller and any depressions shall be filled by adding more stone."

16. Telford Foundations

The function of the Telford foundation is much the same as that of the V-drain but it is a more costly type. It is usually thinner but the stones

are hand placed and more carefully chosen. Usually, of late years, the stones are placed upon a crowned subgrade which is contrary to the theory of Telford, who invariably specified a flat subgrade. Telford is usually laid upon unstable ground as a foundation for broken stone roads, but it is equally well suited for other kinds of paving. The stones used vary from 3 to 8 in in width, 6 to 15 in in length, and from 6 to 8 in in depth. Sometimes a bedding layer of sand or fine gravel 2 in or less in depth is specified but more often the stones are laid directly upon the compacted subgrade. The stones are placed carefully with the widest edge down and the greatest length at right angles to the road axis. The points projecting above the grade of the proposed road crust are knocked off with a hammer, and after filling the spaces between the stones with spalls, the surface is rolled with a heavy roller.

New Jersey Specifications for Telford. Many of the state roads in New Jersey have been built with Telford foundations under the following specifications. "After the road-bed has been formed and rolled, as above specified, and has passed the inspection of the engineer and supervisor, a bottom course of stone, of an average depth of ..... inches, is to be set by hand as a close, firm pavement, the stones to be placed on their broadest edges lengthwise across the road in such manner as to break joints as much as possible, the breadth of the upper edge not to exceed 4 in. The interstices are then to be filled with stone chips, firmly wedged by hand with a hammer, and projecting points broken off. No stone of greater length than 10 in or width of 4 in shall be used, except each alternate stone on outer edge, which shall be double the length of the others and well tied into the bed of the road. All stones with a flat, smooth surface must be broken. The whole surface of this pavement must be subjected to a thoro settling or ramming with heavy sledge hammers, and thoroly rolled with a .... ton ...... roller. No stone larger than 2½ in shall be left loose on top of Telford."

17. V-Drain Foundations

This type, like most of the other forms of foundation in which stones of relatively large dimensions are used, serves a double purpose. It acts as a drain for subsurface water as well as a foundation for the road crust or pavement. See Art. 2.

Mass. Highway Comm.'s Experience with V-Drain Foundations. According to Johnston (44) this type "gave satisfaction in the earlier days, as the traffic did not spread over more than 10 ft except when passing another vehicle. While this practice was satisfactory under the old conditions, it has now been discontinued because it is found that, as the high-speed motor requires more room in passing, the whole width of the road is used. In fact, on main roads the width of the hardened surface has been increased from 15 to 18 ft. One objection to the V-drain is the fact that, owing to the extra depth of stone in the center of the road, the frost action is not as great at that point as at the edges where the stone is lighter, and a considerable distortion is occasioned in the road surface. When the frost enters the ground the lighter sides are raised more than the center with a resulting concave surface; later, when the frost is coming out, the sides thaw out more quickly, and there is an exaggerated camber. These extremes do little or no damage to a surface of gravel macadam, or a soft bituminous matrix, but the more rigid forms of surfacing would be disintegrated. Because of these inherent defects in the V-drain, for several years the Mass. Highway Comm. has been building stone foundation with a flat subgrade."

18. Bituminous Concrete Foundations

Kirschbaum (45a) states that "the use of a bituminous concrete foundation for a bituminous surface is not new; in fact, at one time it was very widely employed. Sections laid between 1880 and 1895 are still in existence in Washington, D. C., Chicago, Omaha, Pittsburgh, Buffalo and Denver, and are giving satisfaction.

Bituminous Concrete vs Cement-Concrete Foundations. "The earth or subgrade is the ultimate support of a pavement. Since foundations are merely means for distributing the load, Portland cement-concrete has, in this respect, the advantage over bituminous concrete. On account of its rigidity or structural strength, the former will distribute the load to the earth with less regard to minor unevenness of density of the subgrade. Furthermore, concrete usually bridges over minor depressions and maintains a surface, the portion having solid contact with the subgrade acting as an abutment for the unsupported area. Should it go down, it will seek its bearing in large slabs or sections maintaining a fairly even contour.

"Bituminous concrete, on the other hand, yields under steady load and seeks, in a much more sensitive manner, to complete its contact with the subgrade. An unevenly compacted subgrade would eventually show in the wearing surface. The use of a bituminous concrete foundation must, therefore, be attended by careful preparation of the subgrade. Uniform compactness must be secured and in all cases there must be provision for thoro drainage. In fact, where the subsoil is not of such character as to maintain itself firmly, it is desirable to specify a course of broken rock, cinders or a thin course of Portland cement-concrete under the bituminous foundation proper.

"The relative rigidity of Portland cement-concrete gives it a low shock-absorbing ability, and pavements not only must support dead-load, but must resist the smashing and impact of traffic. When Portland cement-concrete is used as a foundation for bituminous top, this rigidity causes it to act as an anvil, necessitating the absorption of shocks largely by the wearing surface, concentrating the full effect of smashing blows on this comparatively thin layer. A bituminous concrete foundation, on the other hand, being integral with and of the same plastic character as the wearing surface, having great shock-absorbing capacity, in short will relieve the wearing surface of much of this sort of strain.

"Besides the fact that there are certain practical considerations of construction which favor the use of a bituminous concrete foundation whenever conditions permit, so far as cost is concerned a bituminous concrete foundation is more economical under present price levels. The 5-in bituminous base requires from 22 to 25 lb of asphaltic cement per sq yd, which would cost about 20 to 25 cents. A square yard of 1 : 3 : 6 Portland cement-concrete of the same thickness requires about 53 lb of cement. To be on an even footing as to the cost of the cementing material, Portland cement must be purchased at a price not exceeding $1.30 per bbl." See also (45b).

Portland, Oregon, Specifications for Bituminous Gravel Concrete Foundation are as follows:

"**Materials.** On the rolled subgrade shall be laid a bituminous base consisting of gravel, of which all particles retained on a ¾ or 1-in screen shall be crushed, sand and bituminous cement, conforming to the following percentages by weight:

Aggregate passing 2-in screen and retained on 1-in screen, 5 to 10%;
Aggregate passing 1-in screen and retained on ½-in screen, 23 to 30%;
Aggregate passing ½ in screen and retained on 10-mesh sieve, 27 to 39%;
Aggregate passing 10-mesh sieve and retained on 200-mesh sieve, 18 to 30%;
Aggregate passing 200-mesh sieve, 3 to 5%.
Bituminous cement, 4 to 6%.

"**Mixing.** After the gravel and sand shall have been heated in a rotary mechanical dryer to a temperature of between 121° and 149° C (250° and 300° F) it shall be elevated and passed thru a rotary screen having four or more sections with varying-sized openings, the maximum of which shall be 2 in and the minimum 0.1 in diameter. The several sizes of gravel and sand thus separated by the screen sections shall pass into a bin containing four or more sections or compartments. From this bin the gravel and sand shall be drawn and weighed in the above proportions and passed into a twin pug or other approved form of mixer. In this mixer shall be added sufficient bituminous cement, heated to a temperature of between 121° and 149° C (250° and 300° F), to thoroly coat all particles of gravel and sand, but in no case less than 4% nor more than 6% of the total mixture.

Laying. This mixture shall be hauled to the street and then spread on the prepared subgrade to such a depth that after thoro compression with a road roller allowing a compression of not less than 200 lb per in width of tire, it shall have a thickness of 3 in. Such portions as are inaccessible to the roller shall be tamped with hot tampers.

None of the above base shall be laid in rainy weather nor if the foundation be not thoroly dry."

19. Cement-Concrete Foundations

For all high-grade pavements and particularly in city streets the cement-concrete foundation is undoubtedly the best type. It is rigid and does not shift under the traffic and it has a distinct advantage in its property of bridging over soft places in the subgrade. While sub-drainage should never be neglected, even when a concrete foundation is to be installed, it is a fact that because of its relative imperviability defects in the sub-drainage are often minimized. Concrete foundations vary in thickness from 4 to 8 in under ordinary conditions with 6 in the average and usual thickness in city streets. The factors which control the thickness of the concrete are the subgrade conditions and the intensity of the traffic which the roadway must carry. In ordinary street work a relatively weak concrete is laid, often as lean as 1 part cement to 9 parts of aggregates. It is obvious that a richer mixture, say 1 part cement to 6 parts of aggregates, would be equally effective as a foundation if laid to a lesser thickness than the lean mixture. The upper surface of the concrete should be parallel to the finished surface of the pavement and smooth and uniform. See Sects. 21 and 26.

Reinforced Cement-Concrete Foundations. Experimental investigations by Tucker (61). "The average center concentrated load borne by 6-in plain slabs at 12 days was 1200 lb; by 5-in plain slabs at 11 days, 1125 lb; by the 4-in plain slabs at 10 days, 630 lb. A 2-in slab, reinforced with wire fencing in the middle, averaged 460 lb at 10 days or four-fifths as much as the 4-in plain slab. Three-inch slabs, reinforced near the bottom, gave 1180 lb in 10 days, or the same as the 5-in and nearly as much as the 6-in slabs. Four-inch slabs, also reinforced near the bottom gave 1550 lb in 10 days. One 4-in slab with three wires, at an age of 27 months, gave the remarkable test of 3000 lb. The reinforcement used in every case was ordinary commercial, rectangular-mesh hog-fencing of galvanized wire, costing from 3 to 5 cents per sq yd in place in the street foundation. The slabs tested had either three of four longitudinal wires, just as it happened to come from the top or bottom of the fencing. The meshes ranged between 5 by 6 1/2 and 3 1/2 by 6 1/2 in. The top of the fencing had wires of 1/8 in diameter, while the balance were 9/16 in in diameter, and the transverse knotted stay wires were 7/64 in. The concrete was of the most ordinary sort, made in a hand mixer in proportions of 1 : 4 : 5, with 3/4-in limestone and a coarse and a fine grade of sand in equal parts.

"The outstanding fact plainly shown is that even with this simple and inexpensive reinforcement the 3-in slab is easily as good as the 6-in slab of plain concrete, while the 4-in was about a quarter better. The real significance, economically, of these tests appears when we consider the cash value of the facts learned. Wherever there is need for a 6-in base, one 3 in thick with 5 cents' worth of reinforcement will do equally as well. The cash saving is notable since the concrete will cost from 15 to 20 cents per sq yd per in of thickness. Hence this simple use of hog-fencing means from 40 to 55 cents per sq yd of pavement actually saved, or 25% saving on a pavement costing from \$1.60 to \$2. This would mean a saving of \$1000 upon about 2000 sq yd of pavement, and a small job of paving usually costs several times this amount."

Cement-Concrete vs Broken Stone Foundations. See Art. 14.

Cement-Concrete vs Bituminous Concrete Foundations. See Art. 18.

Penn. State Highway Dept. Specifications for Cement-Concrete Foundations are as follows:

"Description. Upon the prepared subgrade there shall be laid a concrete base course, or foundation, of the depth shown on the plans and in the proposal. This work will be paid for at the contract price per cubic yard for Cement Concrete Base Course complete in place, which price will include all labor, materials, forms and work incidental thereto.

"**Cement-Concrete Base Course and Curb Combined.** Where shown on the plans concrete curbing shall be constructed in conjunction with the concrete base. It shall extend 6 in beyond the edges of the wearing surface and up to its finished grade and shall be composed, with the exception of the top surface, of the same mixture of concrete as is used in the base. The top surface, for a depth of 2 in, shall be composed of a 1 : 2 : 3 mixture. The curb shall be spaded on the outer surface and finished smoothly on the top surface with a wooden float. The curb shall be cut thru to the subgrade at intervals of each 20 lin ft. Forms as specified shall be used on the sides of all curbing during construction. This curbing will be paid for at the contract price per cubic yard for Cement Concrete Base Course complete in place.

"**Composition.** The concrete foundation shall be composed of a mixture of 1 part Portland cement, 3 parts sand or grit and 6 parts crushed stone, gravel or crushed slag. These proportions shall be determined by volumetric measurements.

"**All Water** used under these specifications shall be clean, free from oil, acid, alkali or vegetable matter. Water shall be used in such quantities as will give the consistency called for.

"**Sand** shall be clean and hard grained, and shall contain not more than 5% of loam or other foreign substances. When dry it shall pass a ¼-in screen and shall be graded from coarse to fine, with the coarse particles predominating. An exceedingly fine sand will not be accepted. No bank run sand shall be used under any of these specifications, except upon the approval of the Engineer. Mortar composed of 1 part Portland cement and 3 parts this sand, by weight, when made into briquettes, shall show a tensile strength, at 7 days and 28 days, of not less than 70% of that obtained from briquettes composed of 1 part cement and 3 parts Standard Ottawa sand, by weight. The percentage of water used in making the briquettes of cement and sand shall be such as to produce a mortar of the same consistency as that of the Ottawa sand briquettes of standard consistency. In other respects all briquettes shall be made in accordance with the report of the Com. on 'Uniform Tests of Cement,' Am. Soc. C. E.

"**Stone Grit** shall consist of quartz grains, or other equally hard material from hard, tough, durable crushed rock, having a French coefficient of wear of not less than 15, graded from coarse to fine, with the coarse particles predominating. When dry, it shall pass a ¼-in screen. Not more than 25% shall pass a 50-mesh sieve, nor more than 5% shall pass a 100-mesh sieve. It shall contain not more than 5% of loam or other foreign substances. The tensile strength of briquettes, composed of 1 part cement and 3 parts stone grit, shall be not less than that obtained with Standard Ottawa sand.

"**The Size of the Coarse Aggregate** shall be such as to pass a 1½-in revolving screen and shall range from 1½ in down, not more than 5% passing a ¼-in screen and no intermediate sizes shall be removed. Artificially prepared mixtures of fine and coarse aggregate shall not be used, except when specified or approved in writing.

"**Crushed Stone** shall consist of clean, sound, hard, tough, durable, cubical crushed rock, having a French coefficient of wear of not less than 10.

"**Gravel** shall be composed of clean, hard, durable stone, free from coating of any character. No gravel which contains disintegrated or soft stone, or shale, or an excess of flat pieces, shall be used. Gravel mixed with mud, clay, or other foreign substances, shall be washed in a satisfactory manner and must be approved before being used. Run of bank gravel shall not be used.

"**Crushed Slag** shall be approved slag, clean, sound, tough, hard, and sharp angled. It shall weigh not less than 70 lb per cu ft, loose measurement.

"**Mixing Conditions.** The concrete shall not be mixed in any larger quantity than is required for immediate use and any that has developed initial set, or has been mixed for 30 min, shall not be used in any way. The ingredients shall be free from deleterious substances. Unless directed otherwise, no concrete shall be mixed while the air temperature is at, or below, 1.7° C (35° F). In no case shall any lumped cement or materials containing frost be used, nor shall the concrete be deposited upon a frozen subgrade.

"**Mixing Machine.** Concrete shall be mixed by machinery so as to insure a uniform product of the specified proportions of all the ingredients. The machine shall be a batch mixer of approved type. Continuous mixing machines shall not be used. The mixing shall continue for a period of at least 90 sec after all the materials are in the drum and during the mixing period the drum shall make at least 16 rev per min. The

entire contents shall be removed from the drum before any new materials are placed therein for the succeeding batch.

"Retempering of mortar or concrete which has hardened partially, that is, remixing with or without additional materials or water, will not be permitted.

"Hand Mixing, when permitted, shall be performed on a watertight wooden platform, or other suitable hard, clean surface of sufficient size. The cement and sand, dry, shall be mixed first thoroly, then made into a mortar by gradually adding clean water and hoeing and working until a uniform mixture is secured. The stone shall be spread to a depth of about 6 in, wetted thoroly, and the mortar spread evenly over it. The whole mass then shall be turned over four times and worked until a complete and uniform mixture results. Hand mixed batches shall not exceed ½ cu yd in volume.

"Consistency. The materials for the concrete shall be mixed with sufficient water to produce a mixture which will flatten out and quake, but not flow, when deposited in place. The consistency shall not be such as to cause a separation of the mortar from the coarse aggregate in handling.

"Forms for Concrete Construction. All forms used under these specifications shall be either wooden or metal forms and shall be approved. They shall be free from warp and of sufficient strength to resist springing out of shape when concrete is deposited against them. All joints must be watertight.

"MATERIALS FOR WOODEN FORMS. All wooden forms shall be surfaced plank of at least 2-in stock and of tongue and groove or ship lap style. Where only a single width of plank is used the forms shall be constructed of plain surfaced plank.

"MATERIALS FOR METAL FORMS. All metal forms shall be of not less than ¼-in material, unless otherwise specified, and shall be constructed so as to give a smooth surface, with watertight joints. Where a single width of metal is used, the forms shall be constructed in channel section, or other approved form.

"SETTING. The forms shall be set carefully and staked securely, or otherwise held in place, to the established lines and grades.

"TREATMENT. All wooden forms shall be wetted thoroly or oiled and metal forms oiled before any material is deposited against them. All mortar and dirt shall be removed from forms which have been used previously.

"Placing Concrete. Where the subgrade is very dry or dusty, it shall be sprinkled before the concrete is placed, no more water being used than will be absorbed readily. Concrete shall not be laid on frozen ground. Placing of concrete shall proceed upgrade. The joint of the previous day's work shall be rough in vertical section and shall be wetted or grouted thoroly before the fresh concrete is joined to it. The exposed surface of all inlets, manholes, valve boxes and other structures shall be cleaned of dirt thoroly to permit proper adhesion of concrete. After the concrete is deposited in place, it shall be compacted thoroly by tamping or hoeing, leaving a rough surface for Bituminous Surface Courses and a smooth surface for all other types. When so directed, a template shall be used to strike off the concrete. Rakes shall not be used for distributing or placing concrete.

"Care While Setting. Newly-laid concrete shall be protected from the extreme heat of the sun, or from inclement and cold weather, by one of the following methods:

1. During the hot weather the concrete shall be kept damp by sprinkling with water for a period of at least 3 days following the placing of the concrete, or for a longer period of time, as may be directed.

2. During the season when the temperature of the air can be expected to drop below 4.4° C (40° F), proper precautions shall be taken and if the air temperature reaches 1.7° C (35° F), or below, the concrete shall be protected with an approved covering, of satisfactory depth, for a period of at least 7 days following the placing of the concrete, or for a longer period of time, as may be directed.

"Protection from Traffic. Traffic will not be permitted on the concrete base course until, in the opinion of the Engineer, it has hardened sufficiently to sustain it, and in no case until the last laid concrete is at least 7 days old. The contractor shall protect the finished concrete base course from traffic during this period of setting."

20. Old Pavements as Foundations

Gravel and broken stone roads and stone block pavements, when in reasonably good condition as to thickness and smoothness of surface, are

sometimes used as a foundation for pavements. A gravel base will rarely make a good foundation for an expensive crust or pavement and often it will be found that a broken stone road will require so much cost in preparing it for the wearing surface that it will be inadvisable to use it. It may be safely stated that for expensive pavements, particularly in city streets, the hydraulic cement-concrete foundation is the most economical and practical.

Am. Soc. Mun. Imp. 1915 Specifications for Old Macadam Foundations. "If the pavement is to be laid on an old macadam foundation, the surface shall be thoroly swept and cleaned of all fine material that may be caked upon the surface of the stone or lying loose as dust, thereby exposing the clean, coarse stone for the reception of the bituminous concrete. If the old macadam does not present the desired coarse, grainy surface, or is not at proper and satisfactory grade after cleaning, it shall be spiked up and redressed to the desired crown and grade, the coarse stone being brought to the top by harrowing or otherwise, or new stone added where needed. It shall then be watered and rolled until thoroly compacted. If the result is not the required coarse, grainy surface, a layer of clean stone shall be spread and lightly rolled as described in the paragraph relating to new macadam foundation."

Penn. State Highway Dept. Specifications for Old Telford or Broken Stone Base for Foundation. "Where the old surface consists of a Telford or broken stone base, the surface of which is exposed and which is to be used either as the subgrade for the new foundation, or as the foundation for the new surfacing material, the stones projecting above the new subgrade or base line, as the case may be, shall be broken off with a napping hammer and the depressions and other irregularities brought to a true and even surface by the addition of broken stone compacted thoroly by rolling or ramming. The cost of this work will be included in the contract price for the completed base course when the old surface is used as the new subgrade; or will be included in the contract price for the finished pavement when used as the base course or foundation."

21. Foundations over Marshes

Across marshy places it is inadvisable to lay expensive pavements until the earth in the fills has consolidated and settled, and under some conditions, it is wise to delay the paving for a year or two after the fill is made. When it is not possible to drain swampy land, except at great cost, on account of the topographical conditions, brush or timbers are sometimes laid as a foundation but such expedients are usually unsatisfactory. It is better to spend the money and drain the swamp, or better still, relocate the road and avoid the swamp. No expensive pavement should be placed upon a brush or corduroy foundation.

Methods Recommended by U. S. O. P. R. (50). "The question of ground surface stability usually does not arise as a grading problem except where an embankment is being constructed over very marshy land. If proper precautions are not observed, the embankment material may be absorbed gradually by the marsh until the entire road-bed has disappeared, an occurrence which is not infrequent. Where drainage of the marsh is impracticable, the lower portion of the embankment, which would come in contact with the marsh water, should be formed of some nonslaking material that will cement together and distribute the weight of the embankment over the entire bottom area. Some varieties of gravelly clay are excellent for this purpose. Where the marshy matter is very soft and deep, it may be necessary to lay a wide foundation bed of logs, or fascines, upon which to construct the embankment, but such a foundation bed would not obviate the necessity for using a nonslaking material in the lower portion of the embankment."

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SECTION 9

EARTH AND SAND-CLAY ROADS

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GENERAL DATA

1. Historical Development

Definitions. The principal types of roads to be covered in this Section may be defined as follows:

EARTH ROAD. A roadway composed of natural earthy material.

SAND-CLAY ROAD. A roadway composed of an intimate mixture of sand and clay.

TOPSOIL ROAD. A roadway composed of a natural mixture of sand and clay.

Development (16). "According to recent statistics gathered by the U. S. O. P. R., the aggregate length of all public roads in the United States is, roughly, 2 500 000 miles. Of this total mileage, earth roads comprise about 89.5%, or considerably more than 2 200 000 miles; sand-clay nearly 2%, or 44 000 miles; and gravel about 4.5%, or 116 000 miles, which leaves only about 4%, or about 110 000 miles, for all other types combined. The statistics also show that in the 10 years from 1904 to 1914 the increase in the mileage of improved roads, other than earth, sand-clay, and gravel, has been only from 2 to 3% of the total, and that in states having the greatest mileage of improved roads, only about one-half of their aggregate mileage has yet been improved. From these figures it is evident that the

construction and maintenance of earth roads will continue to be of considerable importance in connection with every comprehensive plan of public road improvement. Also, since sand-clay and gravel surfaces often constitute the first steps from earth roads toward the more highly improved surfaces, either one or both of these simple types may be expected to constitute in the future, as at present, no small part of the total improved mileage in practically every community." Table I shows the development of sand-clay roads from 1909 to 1914.

Table I.—Mileage of Sand-Clay Roads in Several Representative States for 1909 and 1914 (16)

States	Sand-Clay Mileage		States	Sand-Clay Mileage	
	1909	1914		1909	1914
New Jersey	None	561	Kansas	202	758
Virginia	186	1151	North Carolina	730	4313
Alabama	1107	1916	Texas	2254	3684

2. Characteristics

Economic Advantages. As the controlling factor in road construction is usually cost, it can readily be seen that natural soils and such surface formation as clay and sand offer distinct economic advantages on account

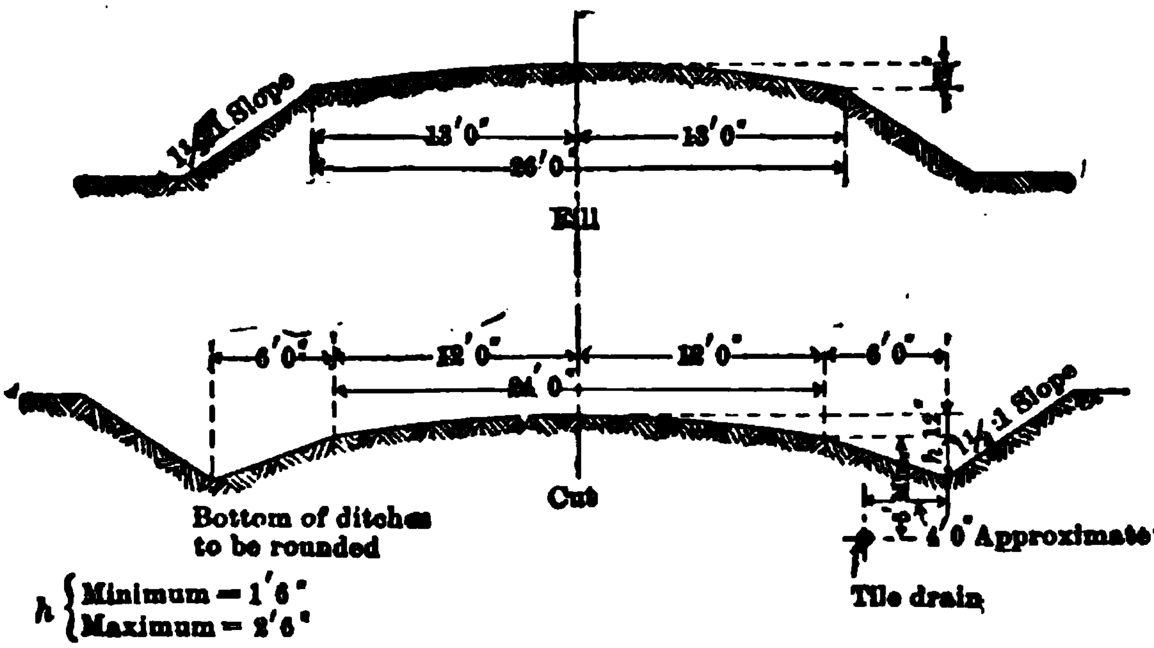

Fig. 1. Iowa State Highway Comm. Standard Cross-Sections for Earth Roads

of: (1) Their abundance and cheapness; (2) their physical condition; (3) their general proximity to the road to be built; (4) the minimum expense and maximum simplicity of the outfit needed for construction work when sand and clay are the surfacing materials.

Suitability. The facts that roads surfaced with such materials can be so constructed that they are practically free from softening under traffic in wet weather, will retain a comparatively smooth surface, are durable, easy of repair at a minimum cost, and can be made to consolidate very

quickly, make these materials highly desirable. Such road surfacing will be confined largely to rural sections or small towns where there is not very severe traffic.

The Life of the sand-clay and topsoil road depends not only on the thickness of the surfacing material and the severity of the traffic, but largely on the method of maintenance. If the suggestions given hereafter are carried out, these roads will last at least 15 years and even longer before they have to be resurfaced.

3. Cross-Sections

Typical cross-sections of earth roads are given in Figs. 1 and 2.

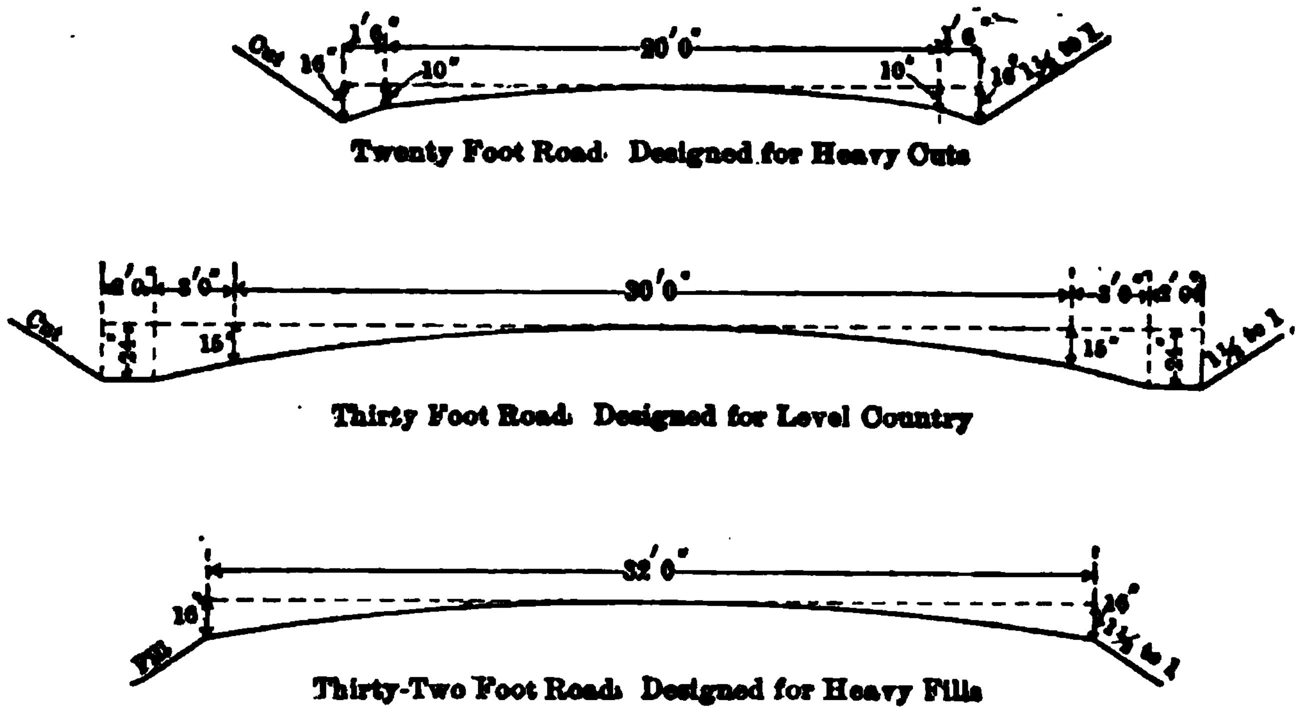

Fig. 2. Cross-Sections of Earth Roads Recommended by the Penn. State Highway Dept.

MATERIALS

4. Physical Properties of Soils

The composition of soils, sands, and of clays must be thoroly understood before the engineer is in a position to obtain the best results in topsoil and sand-clay road surfacing. For this reason, the subject of the composition of these materials is taken up in considerable detail. Too much emphasis cannot be laid on the necessity of having a clear conception of what constitutes a serviceable, natural road soil; what constitutes a good sand or clay to be used in the artificial mixture of these two materials for making a sand-clay road; the necessity of making or having made in advance of its use a definite examination of the material which it is proposed to use for surfacing, and of knowing how to make such additions to inadequate soils of those ingredients which will, with their addition, make the soil adequate and efficient; and the need of making a thoro search for suitable natural soils before adding sand to clay or clay to sand. There is a wide variation in the character of different clays and sands, and the success of the resultant sand-clay or topsoil road depends very largely upon the quality of the sand and clay entering into the construction of

the road surface, and the thoroness with which the component parts are mixed.

U. S. O. P. R. Classification (16). "The principal qualities of soils from the standpoint of road construction depend upon texture and structure, permeability, and capillary power. Soils usually are classified as clay, sand, loam, gravel, marl, or gumbo, according to the material predominating in their composition. Soils composed of two different materials mixed in such proportions that the character of the mixture is decidedly intermediate may be designated conveniently by naming both components, as sand-clay, sand-gumbo, gravelly clay, etc. Reference to Table II, giving approximate bearing powers for different soils, will show that this classification may be of considerable significance in road construction."

Table II.—Approximate Safe Bearing Powers for Different Soils

Kind of soil	Range of bearing power, lb per sq in	Kinds of soil	Range of bearing power, lb per sq in
Dry clay	50 to 80	Moist loam	3 to 10
Moist clay	6 to 50	Dry gumbo	15 to 30
Sand or gravel	25 to 85	Wet gumbo	1 to 10
Dry loam	10 to 20	Marl	Same as clay

Report First Conference, 1917, State Highway Testing Engineers and Chemists. "The committee has been charged with consideration of that large range of natural soils and aggregates which lie below the usual classification of gravel and which in the past 10 years have commended themselves to low cost road surfacing in various sections of the country. The terms sand-clay roads, topsoil roads, and semi-gravel roads have come into road literature as designating various types of construction that utilize either natural surface soil, or sub-surface deposits, or artificial mixtures wherein the chief ingredients are silicious sands and natural clays. The abundant distribution of these two soil ingredients either separately in deposits or already mixed in many soils and substrata, has attracted attention and experiment to an extent which now justifies some attempt at classification and more definite statement of specifications and methods upon which satisfactory results may be predicated.

"The present state of knowledge regarding these materials is derived from the comparative study of the road history under traffic of such roads and the mechanical analysis of the constituent materials. The data secured indicate the necessity of classification and tests based upon a more complete separation of the ingredients than is usually given in a laboratory analysis. Special definitions of the terms sand, silt and clay, are required, also a theory of their mutual inter-action after consolidation. It is believed that the adhesive clay, acting as a binder in dry weather, and as a stopper to capillary openings by swelling in wet weather, must be supplemented by the interlocking strength of the sand aggregate both in dry and in wet weather, to support the weight and the wear of the traffic, while the non-adhesive silt gives aid to density and water resistance. The proportions and sizes of the sand content are highly important for the strength and wearing element. The clay, owing to its expansion under wet conditions, should be present in minimum amount consistent with sufficient adhesion in dry weather; and the silt should form the inert filler for those voids not occupied by the clay. The thoro intermixing of the ingredients is a vital factor, and a process of consolidation which will pack the loose mass from the bottom upward is of much consequence.

"A further conception of the action of this class of materials suggests that the fine aggregate passing a 10-mesh sieve may be regarded as a mortar capable of being used separately to form the road slab, or of carrying any amount of gravel or coarse aggregate up to the point where a complete gravel road is reached with this mortar as its binder. Experience has shown that the addition of coarse material retained on a 10-mesh sieve and less than 2 in in size, provided the coarse material is itself present

in graded sizes, increases the durability of these soil mixtures. Further, the analysis of the fine material passing a 10-mesh sieve in the well known Augusta, Ga., gravel, which possesses excellent binding value, reveals a composition similar to some of the best topsoil roads in that state. There is reason to think that the binders in washed gravel roads might very well be compounded on the same basis as successful soil road mixtures.

"The successful use of these road soil mixtures, whether obtained on the surface, as topsoils, from substrata, or from artificial mixtures of clays and sand, depends primarily on the composition as to size, amount, quality and uniformity of mixing of the three usual ingredients, and upon the adequate consolidation of the mass. From the practical standpoint, the selection of the raw material should not be based on a too narrow analytic figure. The natural deposits are of variable composition. A number of samples from a selected area close to the work may not conform to a specific percentage. But it is usually possible to supplement deficiencies by adding relatively small quantities of sand or clay, as the case may be, and secure in the mixed road bed a fairly uniform material whose analysis is satisfactory. The final acceptance of a material of this class should preferably be based on samples taken at specified intervals on the freshly laid and intermixed road bed and at such other points as the inspector may choose, where the indications are that the mixture is not uniform and satisfactory."

Clays. The function of the clay is to act as a binder, and many experiments have been made to determine the property of the clay, which gives to it a cementing value and why some clays act so much better than others. If a sample of clay is vigorously shaken with water in a wide-mouthed bottle, allowed to settle for 11 min, the turbid water siphoned off to within about 8 cc of the bottom of the bottle, and this operation repeated until a clear liquid is obtained, it will be found that all the clay particles have been siphoned off, leaving behind sand and other impurities of the clay. It has been determined in the laboratory of the Highway Dept. of the Univ. of Georgia, that in this process none of the clay particles siphoned off will have a diameter in excess of 0.01 mm. It is believed that particles of that diameter and smaller are chiefly clay. If this clay which has been separated is digested with water and then allowed to settle 24 hr, it will be found that an extremely fine sediment still remains in suspension in the water. This can be siphoned off, and, if the clay is digested and allowed to settle several times and the wash water siphoned off is evaporated, there is secured a material to which the name colloidal clay has been given. This material is sticky, and it is to this portion of clays that their adhesive value is attributed. Thus, in the utilization of clays as cementing material, a less amount of highly colloidal clay will be required than of a clay containing a smaller percent of this colloidal material.

Shrinkage and Expansion.. Some clays shrink when dried, as shown by the cracking and breaking out of their surfaces. This shrinkage is the measure of their expansion, and expansion makes a sand-clay composition unstable. Shrinkage would do no harm if the clay would stay in this condition, but it does not. When water, removed by evaporation, is restored to the sand-clay mixture, its entrance is accompanied by a simultaneous expansion which causes the grains of sand to become separated. This property can not be overcome, for it is inherent in the clay; but this can be modified, in some measure, by using a less quantity of such a clay and adding another clay with a less percent of colloidal content, for tests that have been made indicate that this shrinkage and expansion of clays is largely a function of this very fine colloidal clay. This expansion of clay under the influence of rain and frost has a very important bearing on the solidity and hardness of the road-bed in whose construction it is used. It therefore becomes necessary to know approximately the colloidal content

of a clay or a soil which is to be used in surfacing a road. The stickiness and plasticity of the clay is a guide as to its colloidal content.

PLASTICITY. A clay is called plastic if it becomes sticky or dough-like when mixed with a certain amount of water, so that it can be molded or pressed into various shapes which it will retain even after it has been dried. If a lump of such clay is put in water, it will usually retain its form for a long time. There are other clays, however, which will immediately fall to pieces when placed in water, as a lump of quick-lime will do under similar conditions. This is due to the very rapid absorption of water into the porous construction of the clay. This characteristic is an important one when considering the material to be used in a sand-clay road.

FUNCTION IN ROAD CONSTRUCTION. The clay is to perform the function in road construction of a weak cement, which will bind together the sand particles. There is but very little trouble in accomplishing this in dry weather. In wet weather, however, clay has a tendency, not only to soften, but to expand, and if too much has been used in the surface mixture, the traffic will cut up the surface and, in the end, cut its way thru the whole thickness, and the road will become muddy. It is approximately estimated that not over 15% of a highly colloidal or sticky clay should be used in the construction of topsoil or sand-clay roads, while the less colloidal clay may run up as high as 28%.

Sands. In the determination of soil or sandy material, that portion which will pass thru a 10-mesh sieve and be retained on a 200, would be classified as a sand. Particles larger than those which will pass a 10-mesh sieve will be classified as gravel. That which passes thru a 200-mesh sieve will be designated as silt, the particles of which have diameters ranging from 0.07 to 0.01 mm. This silt has no adhesive quality, altho, when moist, it has supporting power; but when it is saturated it assumes the character of quicksand. Sand grains, passing a 100-mesh and retained on a 200-mesh sieve, have little value in the construction of a sand-clay surface except as filler between the larger grains of sand. Sand grains, passing a 20-mesh and retained on a 60-mesh sieve, show marked interlocking strength.

COMPOSITION. In the examination of sands, it will be found that there is considerable variation, not only in the size of the grains, but in their outlines, some being very rounded, others angular, and still others with sharp points and edges. The best results in road construction are obtained with sands which have the greatest interlocking strength. This property varies directly with the sharpness and irregularity of the grains. The sand gives the body to the road surface and its resistance to traffic. Sands to be used in sand-clay road construction should, if possible, be free from particles of mica, for this is the most harmful impurity of a sand or clay. If there is more than 3% of mica in the road surface, it will very seriously affect its resistance to wear. The fine flat scales of mica destroy the interlocking value of the grains of sand, as it furnishes not only a smooth, slick surface upon which the grains of sand slide and slip, but also provides an easy access for water, which can penetrate into the surface and thus rapidly soften it. It will be extremely difficult, if not impossible, to obtain a satisfactory road surface with a sand that contains more than 3% of mica. Sand or clay containing any considerable amount of organic matter is also very undesirable, for, altho this would have at first some binding action if used in connection with a sand-clay or topsoil road, its binding properties would very soon disappear and it would act as a sponge to hold moisture.

it would soon begin to decay and, as moisture is one of the products of its decomposition, soft places would develop in the road and the surface become so weakened that it would easily cut thru. It will be economical in the end to go to considerable expense in eliminating the organic matter. Sands also very often contain iron oxide, but this, instead of being a detriment, will aid in cementing the grains of sand.

The STRENGTH of the sand to hold up traffic depends on the size of the grains. The smaller the grains of sand, the less interlocking strength they have, and the more tendency there is for them to powder; the coarser the grains of sand, the greater their interlocking strength, and the stronger, firmer surface obtained, which has more resistance to wear. This is particularly noticeable in wet weather, the road surface that is made with the coarse grains having much less tendency to become soft than the road that is made with fine-grained sands. Where it is impossible to obtain coarse-grained sands, good results can be obtained with the fine sands; but the resultant road will need more maintenance than the other, thus increasing the cost of its upkeep. It will also need far more constant maintenance. Unless a good clay is used for a binder, the resultant road will not be good, no matter how good the sand may be. It will be found that the percentage of sand in these various mixtures will vary from 70 to 90%, and that the clay will vary from 10 to 30%. The coarser grades of sand give the harder road surface, with greater wearing value, and, to get these better results, at least 40% of the sand should be retained on a 60-mesh sieve. If most of the sand passes a 60-mesh sieve, it is practically impossible to get a hard surface. This does not mean, however, that results cannot be obtained with these finer grained sands, such as will be justified by the low cost of the resultant road; but, when used, good service can only be obtained by promptly making repairs. These finer sands do play a part, however, in the construction of the road surface by helping to fill up the voids between the coarser grains of sand, which otherwise would have to be filled with clay, and they also serve to increase the density of the resultant mass and make it still more impervious to water. A sharp, rough sand gives much better results than the same size or even larger grains of rounded sand, because the rough sharp grains are able to interlock much more effectively with each other, which very materially strengthens the road surface. This interlocking quality of the grains of sand lessens the strain on the clay binder. The rounded grains of sand, however, are almost entirely dependent on the clay to cement and hold them together.

Topsoils. Under this head are included all natural soils, composed of sand and clay, that can be used for surfacing materials, either without the addition of any other material or by the addition of small amounts of some ingredient to make the soil an effective surfacing material. In many sections of the country, soils are encountered which are made up largely of clay and sand, having similar properties to the artificial mixtures of sand and clay, and it has been found that certain of these natural mixtures give extremely satisfactory results as surfacing materials for roads. These topsoils vary considerably in character, and many of them which are very similar in appearance to some that have given satisfactory results, are found to be very inferior. It is impossible very often to determine this by its general superficial appearance, but it can readily be determined by analysis.

COMPOSITION. The chief ingredients of these natural soils are gravel, sand, clay, silt, mica, feldspar, lime, iron salts, and organic matter. Upon

the percentage of these various ingredients and upon the size of the particles depends the value of the soil for road surfacing purposes. A large proportion of sand-clay mixtures has been derived from the decomposition and disintegration of igneous and metamorphic rocks, principally granitic and gneissic, which are composed of quartz and feldspar, with varying amounts of several other minerals. As these rocks decompose, the feldspar changes to clay and quartz, the original quartz remaining unaltered. Occasionally granitic rocks are found in place which are thoroly altered and decomposed to a depth of 50 or more feet. Certain portions of this decomposed rock contain the right proportion of sand, quartz grains, and clay to make a very satisfactory road surface. In other portions, the clay is in excess. There is given in Table III analyses of several samples of topsoil.

Table III.—Typical Georgia Road Soils (25)

Sample No.	County	Diameters in Millimeters							
		Gravel	Sand					Silt	Clay
		Above 1.85	1.85 to 0.86	0.86 to 0.24	0.24 to 0.14	0.14 to 0.07	Total	0.07 to 0.01	0.01 to 0.00
476	Cobb	4.0	8.0	33.0	17.6	13.6	71.2	15.0	14.0
466	McDuffie	13.0	19.6	44.6	8.0	6.0	78.2	4.5	15.0
150	Clarke	8.0	8.5	36.0	12.5	11.3	68.3	12.2	11.0
10	Clarke	....	7.8	34.3	9.2	9.0	60.3	12.8	25.0
108	Dougherty	0.8	0.8	30.1	15.4	20.0	66.3	14.1	18.0
124	Sumter	....	8.0	22.0	14.7	15.3	56.6	14.6	27.5
424	Muscogee	....	2.8	8.3	18.4	25.0	54.5	12.4	31.0
120	Bulloch	10.4	4.6	22.0	14.7	15.3	56.6	14.6	27.5
106	Bulloch	10.0	4.0	30.0	18.5	12.1	64.6	18.6	20.0
484	Emanuel	....	2.4	9.2	19.7	27.0	58.3	12.8	25.0
103	Brooks	....	2.7	20.7	21.2	26.4	71.0	14.8	14.2
113	Mitchell	....	2.0	32.0	20.8	17.4	72.2	13.4	14.0
	Special								
470	Augusta Gravel	15.2	28.0	54.4	6.0	2.2	90.6	3.4	6.7
116	Pipe Clay	....	14.3	16.9	4.8	4.7	40.7	8.8	50.0
	Passing Sieve	10-mesh	20-mesh	60-mesh	100-mesh	200-mesh			

Notes Explanatory of Table III. There is given below a brief statement regarding the samples analyzed as to where they were obtained and how used.

Sample No. 476. Atlanta-Marietta Road, Cobb County. Taken in 1914 from road-bed. Topsoil. Very hard and smooth. Not cutting. Heavy traffic. Age, 1 year.

Sample No. 466. Thompson-Augusta Road, McDuffie County. Taken from road-bed, 1913. Topsoil. Very hard and smooth. No mud. Heavy auto traffic. Age, 1 year.

Sample No. 150. Athens-Danielsville Road, Clarke County. Taken from road-bed in 1912. Topsoil. Very hard and smooth. No cutting. Heavy traffic. Age, 5 years. Repairs not above $10 per mile. Best in Clarke County.

Sample No. 10. Athens-Whitehall Road, Clarke County. Taken from road-bed in 1911. Topsoil. Hard and smooth. Softens a little. No deep mud. Age, 6 years. Condition good. Repairs no more than $25 per mile. Medium traffic, mostly automobile.

Sample No. 108. Albany-Thomasville Road, Dougherty County. Taken from road-bed, 1911. Age 3 years. Softens slightly and washes. Very smooth, hard surface when dry. Some dust. Substratum natural sand-clay. Medium traffic. Not the best in this county.

Sample No. 124. Americus-Albany Road, Sumter County. Taken from road-bed, 1911. Very good and smooth; washes and softens somewhat in rains. Is dragged after every rain. Substratum, sand-clay. Medium traffic. Repairs about $35 per mile annually.

Sample No. 424. Muscogee County. Taken from road-bed, 1911. Medium hard when dry. Gets dusty. Softens in rain, and washes. Topsoil. Better soils are now being used in this county.

Sample No. 106. Statesboro-Savannah Road, Bulloch County. Taken from road-bed, 1911. Gravelly topsoil. Very hard and durable. No cutting roadbed.

Sample No. 434. Emanuel County. Taken from road-bed, 1911. Good surface but cuts easily. No deep mud. Repaired by drags. Substrata sand-clay.

Sample No. 103. Near Quitman, Brooks County. Taken from road-bed, 1911. Good smooth surface in dry weather, workable by road machines. Softens in wet weather but no mud. Some organic matter when sample was taken. Topsoil. Medium traffic.

Sample No. 113. Near Pelham, Mitchell County. Taken from road-bed, 1911. Hard surface. Strong clay binder. Workable with road machine after rains. Some organic matter. Medium traffic. One of the best South Georgia roads examined. Topsoil.

Composition for Road Construction. A topsoil is sometimes found which has exactly the right composition to give first-class results as a surfacing material. At other times, it is found upon examination that the topsoil will give excellent results if certain materials in which it is deficient are added. Thus, a topsoil that is a little bit too sandy may be brought to the right condition by plowing into it a little of the clay subsoil and by thoroly mixing the two together by plowing and harrowing. If, on the other hand, the topsoil contains a slight excess of clay, this can be remedied by hauling a certain amount of sand and thoroly incorporating this with the original material. In many instances a topsoil is found that, as far as the percentage of the ingredients is concerned, is just right for a surfacing material, but the sand is too fine grained. The road resulting from the use of such material will be of medium hardness and will need frequent dragging.

Semi-Gravel Soils. Some of these soils contain so much gravel that they might be called semi-gravel soils. Gravel exceeding 2 or 3 in in diameter is objectionable in a soil, which is to be used for a road surface, and should, if possible, be removed while loading, or raked out after being placed on the road, or worked to the bottom of the layer of soil. Ten to 15% of gravel passing a 1-in screen and retained on a 10-mesh sieve, increases the efficiency of the resultant road surface.

As in a true gravel, the hardness and quality of the component parts of the semi-gravel must be carefully examined and determined. Occasionally such a gravel is found to contain a great deal of either fresh or partially decomposed feldspar, this being especially true in material that is derived by the alteration and decomposition of granitic rocks in place. Such semi-gravels also very often contain masses of micaceous material and of nodules of indurated clay. Any considerable percentage of any of these will become undesirable elements of the surfacing material, as they are all too soft and readily break down under traffic.

Value of Laboratory Tests. While it is not necessary to make a laboratory test of all samples of topsoils that it is desired to use in surfacing roads, yet field tests should be made in all cases to determine the value of such soils for this purpose. The soils should first be examined as to their mica content and whether they contain any appreciable amount of organic matter. If these are absent, the soil should be tested similarly as is suggested for mixtures of sand and clay, by making a paste of the

soil, then moulding it into small cones, drying them in the sun and then covering them with water. Those that retain their shape for some time and only gradually go to pieces, can be used to advantage in road surfacing.

Too much emphasis cannot be laid upon the necessity of testing these road materials before using them, for if this is not done, the chances are that inferior soils, clays and sands will be used to the detriment of the road.

Essential Properties. The field and laboratory experiments which have been made would seem to justify the following conclusions:

1. That 60 to 80% of sand is necessary to obtain a hard surface, and that the best soils will contain 45 to 50% of sand retained on a 60-mesh sieve.

2. That sand passing a 100-mesh and retained on a 200-mesh sieve has little hardening value to the road surface, but does aid in filling the voids; and that roads constructed only of sand of this fineness will not be satisfactory.

3. That when less than 40% of sand passes a 60-mesh sieve, the resulting road surface is very noticeably softer than where the coarser sand is used.

4. That if there can be 10 to 15% of gravel, varying from that which passes a 1-in screen and is retained on a 10-mesh sieve, it has a very decided effect in increasing the hardness and efficiency of the road.

5. For the best results, the clay will vary from 10 to 20%.

6. An excess of 30% of clay in the soil will give a soft surface that will get very muddy in wet weather.

5. Sampling of Soils

First Conference, 1917, State Highway Engineers and Chemists Method. "Samples of materials of this class shall be of two kinds: Class 1, samples of the raw material taken from the natural deposit; Class 2, samples of the loose material after being mixed in place on the road-bed and before consolidation. Class 1 sample shall be used simply as preliminary evidence of the suitability of the aggregate subject to admixture of one or more ingredients to adjust the composition to the limits set forth in the specifications. The final acceptance of the material as satisfying the specifications shall be based on Class 2 samples.

"Standard Containers. (1) A three-compartment box of pasteboard, wood or metal, outside dimensions 5 by 10 by 10 in, or (2) close woven bags or sacks of material which do not allow sifting out of fine particles, dimensions 6 in wide by 12 in long.

"Labeling. Each compartment in the box container must contain a label showing at what depth the contents were taken. The whole sample shall be accompanied by a card, securely attached thereto, stating date, by whom taken, by whom submitted, source of supply, exact location where sample was taken, position within the deposit where taken, owner, quantity available, amount and character of stripping, if any, whether material from same source has been previously used, where, and with what results, haul to nearest point on road, average haul to job, character of haul, initial cost of material. When bag containers are used, one complete sample shall comprise three bags, each bag labeled as to depth from which the material is taken. Each bag, or, if preferred, a larger receptacle containing the three bags, is to be labeled with the information detailed above.

"How to Take Class 1 Samples. For each 1 acre or less of area, two samples must be taken, one a local sample and the other a composite sample. The local sample is to be taken near the center of the area, and is intended to represent the vertical average of the material at that point. It shall be taken in three layers, each layer .... inches thick, according to the method described as follows: The material is to be loosened over a 3 by 3 ft area to the specified depth, usually 4 in. The loose material is to be intermixed with a shovel and the sample for one compartment of the box container or one of the bags is to be taken therefrom. The remaining loose material is to be

shoveled out and discarded. The second layer is to be loosened to equal depth, usually 4 in, to be intermixed as before, and a second compartment or bag is to be filled. The same procedure shall apply to the third layer, and the filling of the third compartment or bag. In exceptionally thick deposits the depth of each layer or the number of layers may be increased to cover the entire thickness of the deposit.

"The composite sample is to be taken as follows: Roughly divide the area to be represented by the sample into squares not exceeding 50 ft in size. At the corners of all squares loosen a 3 by 3 ft area to a depth of .... inches; a depth of 8 in is suggested. Thoroly mix the loose material. Carry an equal amount of the material from each such point to a central point and intimately mix the various samples. Not less than 200 lb of material must be mixed. From the center of the pile of mixed material fill a container and label for shipment. Where the material occurs as a substratum sink no less than four 3 by 3 ft pits per acre or smaller area to intersect the material. Remove the covering and sample the exposed bed as for a local sample described above.

"HOW TO TAKE CLASS 2 SAMPLES. These are the most important samples, and should be taken by the engineer or competent inspector while work is in progress. When the materials have been spread and intimately mixed in accordance with properly drawn clauses covering methods of construction, the engineer should fill a container at intervals of .... feet, along the road, and also at such other points as his judgment may dictate, where evidence of unsatisfactory mixing is apparent. Intervals of 500 ft are suggested. Very prompt examination of these samples should be made in order that defects of composition may be remedied by the builder before consolidation has progressed."

6. Testing Soils

Field Tests. In actual road construction, it is not always possible to make a long laboratory test regarding the character of the clay and sand, and tests very often have to be made in the field. Rapid and very satisfactory tests can be made as follows: Samples of the available clays and sands should be taken and mixtures made of these, varying from 1 part sand and 1 part clay to 6 parts sand and 1 part clay. These mixtures should be worked up with water into a putty-like mass, and then rolled into small spheres or cones, and placed in the sun to dry. After these have become thoroly baked, they should be placed in a flat pan and enough water carefully poured into the pan to cover them. Care should be taken not to pour the water directly on the samples. It will be noticed that some samples will break down almost immediately, while others break down very slowly. These latter ones will represent combinations that should give good results as road surfacing mixtures, and the quantities of sand to add to the clay can be determined from these.

The proportion of sand and clay in the best sand-clay road should be such that there is just a sufficient amount of clay, and no more, to fill the voids between the grains of sand when these grains are touching each other. The clay is the binder that is to hold the grains of sand in place and there should not be any more than is sufficient for this purpose. If too large a proportion of clay is used, the grains of sand are prevented from touching each other and are able to move about each other in the mass of clay so that the resistance of the mass to the wearing effect of traffic is practically no more than if the road was composed simply of clay. Water is also able to act upon the mass of clay and the road becomes sticky and muddy. If there is too small a proportion of clay used, the grains of sand are not cemented tightly together and the road disintegrates very quickly under traffic and rain.

The exact proportions of sand and clay for making the best sand-clay road can not be stated, as the proportions vary with the character of the

sand, according to its sharpness, percentage of foreign material and size of grains. One simple means of determining the theoretical amount of pure clay, which should be added to any sand to be used in the construction of a sand-clay road, is to fill a glass tumbler brimful with the sand that is to be used; then fill a similar tumbler with water; pour the water carefully onto the sand until the water comes flush with the surface, which will mean that all the voids between the grains of sand are filled with water. The amount of water that has been poured into the tumbler containing the sand will represent the proportion by volume of clay that it is necessary to add to that particular sand to fill all the voids with clay.

Laboratory Tests. CLAY IN SAND-CLAY MIXTURES (26). "The following method has been used satisfactorily in determining the excess of clay in a natural sand-clay mixture:

1. Measure out about 1000 cc of the material in a conical graduate. Tap the glass with the hand for a few minutes and record the amount.

2. Grind the measured material as fine as possible with mortar and pestle. Note: Road traffic will provide more wear than this.

3. Wash the gravel thoroly in shallow pans and allow it to dry. Keep the water containing the clay, allow it to settle or flocculate it, decant, measure, and report the reading.

4. Put the dry washed sand in the flaring graduate, tap firmly with the hand, and pour from a measured quantity of water into the vessel, permitting it to run slowly down the glass on one side until the voids are filled. Label the material and record the amount of water used.

5. Compute the percentage of voids, the amount of excess clay, and the additional percentage of stream sand necessary to utilize the excess clay.

6. Tabulate results as follows:

No. of Test	Original Volume cc	Clay Washed Out cc	Sand Remaining cc	Water Filling Voids cc	Volume of Voids Percent	Excess Clay cc	Stream Sand Neces'y Percent
4	1200	330	800	225	31.9	75	17.3
10	2100	760	1220	452	37.0	308	39.6
11	800	263	650	212	32.6	51	17.7
12	1000	125	805	243	30.2	0	0.0

These samples were taken from various levels of a pit in a decomposed granite at Chapel Hill."

First Conference, 1917, State Highway Engineers and Chemists Method for Analyzing Soils. "Dry 500 g of the material at a temperature below 177° C (350° F) to constant weight. Gently pulverize to break down soft clods or masses, but not to grind or break hard material. Pass thru a 10-mesh sieve, weigh the coarse residue and record as coarse material. Use the material passing the 10-mesh sieve as the starting point of a percentage analysis as follows: Weigh out two samples of 50 g of this material for duplicate analysis. Place each in a wide mouth bottle, 5 to 6 cm diameter and about 12 to 15 cm high. Add about 5 cc of dilute ammonia water and about 200 cc of water. Close with a cork or glass stopper and shake thoroly for 20 min. Allow the sample to settle 8 min, and decant carefully or siphon off the supernatant liquid to a depth of 8 cm below the surface of the liquid. The depth of the liquid in the bottle should be sufficient to leave about 4 cm below the point of siphoning. Fill the bottle again with water, shake for 3 min, allow settlement and siphon off, as before. Repeat the process until the supernatant liquid is clear. Be careful to wash the stopper and neck of the bottle free from coarse material before decanting. The washings drawn off may be collected and evaporated to dryness for direct recovery of the fine sediment classed as clay. Ordinarily the sediment loss or clay is computed as difference. Wash the contents of the bottle cleanly into a porcelain evaporating dish and carry

to dryness on a water bath. The dried residue should be carefully scraped from the dish and passed thru a nest of 20, 06, 100 and 200-mesh sieves. The residue retained on each sieve is weighed and recorded as sand of the respective sizes. Their sum constitutes the total sand. The residue passing the 200-mesh sieve and caught in the pan is weighed and recorded as silt. Duplicate samples should check within 1%.

1. The coarse material should be examined for hardness and with the magnifying glass to identify its character as quartz, hard-iron compounds, feldspar, schistose material or indurated clay. Hard quartz or iron gravels are valuable in themselves and as indicating the quality of the finer aggregate. Feldspar, mica and clay nodules are worthless, and indicate that the accompanying soil is poor for road building.

2. The sands should be examined with the magnifying glass for identification as quartz, and for the presence of mica scales or feldspar needles. If mica or feldspar is present in appreciable amounts the sample should be rejected.

3. When the clay is recovered by evaporation, it can be examined for tenacity by cementing together two glass plates, each 1 in wide set at right angles, with a layer of clay whose thickness is fixed by a fine bent wire laid between the plates. The moist clay covers the wire on one plate and the other plate is squeezed down tightly on the wire. After drying, the one plate being held firmly against cleats, wire slings are run symmetrically from the ends of the upper plate to one arm of a beam balance, and the tension necessary to separate the plates is given by shot or weights in the other pan of the balance. This test is tedious and is of service chiefly on low grade samples which are of doubtful efficiency, but which represent the only available material for local construction.

4. Approximate tests for tenacity of mixture can be made as follows: Make cylinders from the material passing the 10-mesh sieve, 25 by 25 mm. The material is worked into a stiff mud, and molded under 132 kg per sq cm pressure. Dry thoroly at 100° C (212° F) and break by the small Page impact machine using a 1 kg hammer and 1 cm drop. Record the number of strokes as the relative measure of tenacity. Mix 50 g of the material passing the 10-mesh sieve with .... grams of water and knead with the hands into a spherical ball. Measure the diameter. Let this ball drop from a height of .... centimeters on a flat slab. Measure and record the reduction in diameter and examine the surface for cracks. Usually the plastic character and adhesiveness of a good road soil can be judged by the feeling of the mud made from this material, its adherence to the hands, and its stretch under light pulling."

7. Specifications for Soils

First Conference, 1917, State Highway Engineers and Chemists Specifications. "The terms, clay, silt, and coarse material, used in this specification, are defined as follows:

Clay, material separated by subsidence thru water and possessing plastic or adhesive properties, generally below 0.01 mm diameter.

Silt, fine material, other than clay, which passes a 200-mesh sieve, generally from 0.07 to 0.01 mm diameter.

Sand, hard material, usually silicious, which passes a 10-mesh sieve and is retained on a 200-mesh sieve, generally from 1.85 to 0.07 mm diameter.

Coarse material, hard material of gravelly nature, retained on 10-mesh sieve, that is more than 1.85 mm diameter.

"Physical Properties Coarse Material. The coarse material, if any, of the aggregate, shall consist of hard, silicious material, free from feldspar, mica, schist, hard-pan, or other soft, friable material, in excess of 5%.

"Mechanical Analysis of Material Passing 10-mesh Sieve. The material which will pass a 10-mesh sieve, when subjected to mechanical analysis, shall meet the following requirements:

Clay....................................	...% to ...%.
Silt.....................................	...% to ...%.
Total sand..............................	...% to ...%.
Sand retained on 60-mesh sieve..........	...% to ...%.

"Notes. To cover the range of materials adaptable for road construction, it is recommended that roads of these types be divided into three classes, designated, Hard or Class A, Medium or Class B, and Soft or Class C, according to the mechanical

analysis of the material which is to be specified for use. The limiting percentages of the constituents suggested for the three classes are as follows:

	Hard or Class A	Medium or Class B	Soft or Class C
Clay	9 to 15%	15 to 25%	10 to 25%
Silt	5 to 15%	10 to 20%	10 to 20%
Total sand	65 to 80%	60 to 70%	55 to 80%
Sand retained on 60-mesh sieve	45 to 60%	30 to 45%	15 to 30%"

CONSTRUCTION

8. Fundamental Principles of Construction

In the construction of a topsoil or sand-clay road, there are certain fundamental principles that must be kept constantly in mind:

1. That it is necessary to secure a natural soil or to make an artificial mixture of the right composition.
2. That a sufficient quantity of the material should be deposited in one layer, if it is topsoil, and to have one thick layer of the mixed materials before any traffic goes over it.
3. That the materials must be thoroly mixed together before consolidation is attempted.
4. That in packing this material, it should start from the bottom upwards.
5. That during packing the road should be watched carefully so that all depressions can be filled up, and that by the constant use of the road machine the proper shape and crown can be maintained.
6. That it is absolutely necessary for the materials to be thoroly puddled before they will cement satisfactorily.

While it may not be possible in all cases to carry out the above completely, yet it must be realized that this must be done if the best results are to be obtained.

9. Construction of Earth Roads

For many generations to come it will be impossible for many communities to surface all of their public roads; this means that there will be many miles of earth road to be constructed and maintained. These earth roads will not have very severe traffic as they will represent largely secondary roads. When properly constructed, the earth road can, by systematic maintenance, be kept in good condition during all periods of the year which are free from freezing and thawing. The same principles regarding selection and grading should apply to the earth road as to the roads that are to be surfaced. This is especially true in those sections where roads are being constructed which are to be utilized as earth roads for a certain length of time with the expectation, at the end of such time, of surfacing them. The earth road is much more susceptible to damage by water than any other road, and more vigilance is necessary to keep the water off the road-bed. Therefore, in constructing the earth road the crown of the road is usually somewhat steeper than in other types of road. The slope from the center to the side ditches should be from 1 to 12, to 1 to 20. In grading the earth road, if there are any grades over 4½%, it will be necessary to construct

across the surface of the road a V-shaped surface ditch to turn the water off the surface of the road, for unless this is done the water will run down the road, following any depressions made by the wheels of traffic.

U. S. O. P. R. Method (16). "The work of constructing an earth road, after the general location and design have been decided upon, may be separated into six more or less distinct operations, as follows: (1) The work is staked out in accordance with previously prepared plans; (2) the right-of-way is cleared of all trees, brush, stumps, etc, which would interfere in any way with the work; (3) all necessary bridges, culverts, drains, and other structures which extend under the road surface are constructed in accordance with proper designs; (4) the road-bed is brought to the required width and grade by making excavations and constructing embankments; (5) the surface is finished to the required cross-section and so maintained until compacted thoroly; (6) all necessary outlet ditches, gutters, guard rails, fences, etc, are constructed in accordance with the plans.

"GRADING. The grading of an earth road includes all excavating, hauling, and filling necessary in constructing the road-bed slopes, side ditches, etc, and usually is by far the largest item of work connected with earth-road construction. The most economical methods and machinery to employ in grading a particular road depend on the character and amount of the work to be done. Where, for example, the grade and cross-section of the road follow closely the original ground surface most of the necessary grading usually may be done with a grading machine. In the case of embankments, built up with material from borrow pits along the sides of the road, an elevating grader frequently may be used to advantage. If material must be moved longitudinally along the road from cuts to fills in order to bring the surface of the road to the required grade, the work usually must be done either with scrapers or dump wagons. Where a considerable volume of material is to be excavated in a relatively short distance a small steam shovel with dump-wagon equipment sometimes may be employed economically.

"The method of operating a grading machine necessarily will have to be modified at times in order to meet special conditions. Where, for example, the ditch area is covered with heavy sod or contains a number of large roots, it may be very desirable to plow this area and cut the roots with an ax before using the grading machine. If this is done the plow furrows should be turned toward the center of the road and the line of the initial furrows should be controlled by two rows of stakes. If the sod is very tenacious it should be harrowed with a disk harrow ahead of the grading machine, and after the material has been moved over toward the center of the road the lumps of sod should be thrown out. A method sometimes followed is to skim off the sod, by means of hand shovels, ahead of the grading machine, but this method is expensive and seldom justified. Whether or not it is necessary to contend with any considerable quantity of sod, the use of a disk harrow usually will prove helpful in securing a smooth uniform road surface with the grading machine. In general it is sufficient to give the loosened material a thoro harrowing after the road has been brought approximately to its required shape, but before the final shaping is done. Where continuous long stretches of road are to be graded with grading machines, it frequently is economical to substitute a traction engine for the teams and to employ two machines. Where this is done the first machine is connected immediately behind the tractor, either directly behind or to one side, as the conditions require, and the second machine is connected behind and to one side of the first. Otherwise the method of operation is not essentially different from that already described. The rate at which a road can be graded up with a grading machine varies to a great extent, and depends largely on the character of the soil. Where the original cross-section of the ground is approximately level, and the soil conditions not unfavorable, a grading machine drawn by six well-trained horses should cut out the side ditches and shape the road in from 20 to 35 round trips. Allowing for a reasonable amount of lost time, the rate at which the team travels should average from 1½ to 2 miles per hr, and under the circumstances assumed above, the length of road graded per day should average not less than ¼ mile. Such favorable conditions seldom are found for any considerable stretch of road, except in the prairie sections of the Middle West, and the average rate of grading with a grading machine is, therefore, much less than ¼ mile of road per day.

"FINISHING THE SURFACE. No matter how the grading of an earth road may be

accomplished it usually is economical to bring the road surface to its final shape by means of a grading machine. In making excavations it is not generally considered practicable to form the crown and side ditches with scrapers or hand tools alone, and the cross-section is, therefore, frequently left approximately flat. The grading machine is then used to produce the required cross-section. After the road has been finished with the grading machine, it should be given frequent attention until the embankments have finished settling and the surface has become thoroly compacted by the action of traffic. Generally a period of several months should elapse after a road is graded before it is considered complete, and such settlements and irregularities as develop during this period should be corrected by the use of either a grading machine or a road drag."

Iowa Standards and Methods (5). "CROSS-SECTION. Crown. Ample side ditches are necessary for removing rainfall and water from melting snow. The amount of slope that can be given to the cross-section of the traveled way is limited by considerations of the safety and comfort of those who travel the road, and should not exceed about 1 in per ft. When the circular arc cross-section is used, the slope increases from the middle of the road to the ditch line, as is proper. It has frequently been stated that the cross slope should be greater on hills than on the level, and while that is desirable from the standpoint of drainage, it is exceedingly undesirable from the standpoint of safety, whether the traffic be made up of motor vehicles or horse-drawn vehicles. The tendency to slide is greater on hillsides than on the level, and the results of skidding or sliding to the ditch much more aggravating.

"Width of Traveled Way. For slow moving vehicles a comparatively narrow track is all that is necessary, but for mixed traffic, a part of which moves at relatively high speed, plenty of room is desirable; and such traffic is encountered on most of our country roads. For first-class roads, the traveled way should not be less than 24 ft wide, and for secondary roads, not less than 20 ft wide. The roadway should have a circular arc cross-section with a crown of an average of 1 in per ft from the center line to the shoulder line.

"Ditches. Beyond the shoulder line the ditch should have a width great enough to give an easy slope from the shoulder line to the bottom of the ditch. Safety demands that this slope be such that in an emergency a vehicle might turn out into the ditch without danger of overturning. The minimum width of ditch should be about 6 ft, with a back slope of 1½ on 1, but with some soils it may be 1 on 1, or as steep as the soil will stand. Besides fulfilling the considerations before mentioned, the type of cross-section adopted should be one that can be readily constructed with ordinary earth-working machinery. For that reason, the V-section should be used for the ditch rather than the trapezoidal section. The rate of grade at which it is desirable to change the size of ditch is a matter of judgment and experience, but it is believed that for grades up to 2% there should be little change, particularly if there is any snowfall to be considered. Above 2% the ditch may be of somewhat less capacity than for lighter grades. A still further reduction in the ditch capacity may be made at about the grade where erosion begins; and usually for permanent construction the ditch is paved, or erosion prevented by lateral dams or check weirs such as are used in irrigation ditches. Erosion usually begins with grades of about 4%, altho this is exceedingly variable, dependent upon the type of soil.

"Iowa Standards. The cross-sections used by the Iowa Highway Comm. are shown in Fig. 1 and illustrate the general application of the principles enumerated above. Finally, the cross-section should be so designed that when the road is surfaced with macadam, concrete, brick, or other hard material, no great amount of earthwork will be necessary to prepare the earth foundation for the hard surface. It is desirable to have a little excess crown in the earth road so that by the time enough material has been removed to true up the foundation the crown will have been reduced to the proper amount for the hard surface.

"PROFILES. One of the most troublesome problems in the design of earth roads is encountered when the grade line is being established. Where existing grades exceed 3%, and they are often as great as 5 or 6%, it is usually not difficult to determine just how much to change grades, and the official, with whom the engineer must deal, will agree to almost any reasonable change. But in rolling country the profile of the road is a succession of knolls with none of the grades exceeding 2 or 3%, and it is often difficult to convince non-technical boards that any change in the profile of such a

road is economical. On such roads the difference in elevation between the two ends of a mile of road may be only a few feet, yet a vehicle may have traveled a vertical distance of four or five times that amount in the mile. If any saving in this latter expenditure of energy can be made it is a saving which goes on for all time; and a community could more rationally issue long-term bonds for grade reduction than for any other form of road improvement.

"Limiting Grades. The maximum grade should not exceed 4% but in exceptional cases it may be as great as 6%. If a grade of 6% or less cannot be secured, the possibility of relocation should be investigated, and if feasible, a recommendation for relocation should be made.

"Alignment. If a grade of 3% or greater, is more than 400 ft long, there should be a level section 25 ft long introduced at approximately the half-way point. If there is a deflection of more than 60° in alignment on a grade of 3% or greater, considerations of safety demand that the grade line be made level for the length of the curve.

"Grade Crossings. At railroad crossings the grade line should be a straight line across rail heads for 30 ft on each side of the middle of the track, and should be connected with the grade line beyond by suitable curves.

"Verticle Curves. At breaks in the grade line the transition should be made by means of a circular arc, tangent to the two sections of grade line and having a length in feet of approximately 25 times the algebraic difference in grade of the two sections.

"Grade Reduction. It is desirable to reduce the total vertical rise to as low an amount per mile as practical. As a guide it may be assumed that it pays to move from 100 to 150 cu yd of earth to make a reduction in grade amounting to 1 ft per mile. This allowance may be increased if heavy grading is necessary on part of the mile to bring the profile to the limiting grade. Short, sharp undulations in the grade line should be eliminated as far as possible. Safety should be an important consideration and a clear view should always be possible at a distance of at least 250 ft. Any grade line that precludes this should be revised.

"Use of the Elevating Grader. If a road is designed in accordance with the above principles particularly as regards cross-sections, the elevating grader can be used to good advantage in the construction. In general, the work to be done consists in rounding up the traveled portion of the road with material obtained from the side ditches. The best results will be obtained in flat country or slightly rolling country, where sections of a mile or more in length can be constructed at one time, thus obviating frequent turning of the outfit.

"Classes of Road Work for Elevating Grader. There are the three following classes of roads encountered in the various counties in Iowa where the elevating grader has proven satisfactory:

1. Roads practically level where the new grade line is parallel to the profile on the old road, there being only a few knolls to be removed.
2. Roads on which there are a succession of knolls and consequently a succession of cuts and fills most of which do not exceed about 2 ft in depth.
3. Roads where extensive grade reduction work must be done.

"Grader Outfits. The outfit necessary for roads of Class 1 consists of the elevating grader drawn by 6 or 8 teams or by a tractor, a blade grader, a few slips or wheelers, a heavy disk harrow, a heavy straight-tooth harrow, and a split log or plank drag. If a roller is also available a better road can be constructed than is possible without it. For roads of Classes 2 and 3, a number of dump wagons are also necessary.

"Construction Methods. In starting the construction the first cut is taken at the shoulder line, and the material thus removed is deposited near the shoulder line of the opposite side of the road, but, of course, in the roadway. Stakes are set for the first cut so that the driver can follow them conveniently. If the outfit is horse-drawn, the stakes are set so that the tongue of the elevating grader will follow them. If the grader is drawn by a tractor, they are set so that the front wheel on the steering side will follow them. The exact distance of these stakes from the line of the cut will vary somewhat with the type of elevating grader used and must be determined before the stakes are set. The first cut is a light one and usually one horse of the lead team follows this first furrow and thereby guides the grader in making the succeeding cut. If the grader is drawn by a tractor, a side hitch is used so that the tractor travels on the land side, and a plumb bob is hung from the tractor in such a position that it will follow the furrow and thus serve to assist the driver in steering.

"On roads of Class 1, the successive rounds of the elevating grader are made without reference to the slight knolls that occur; and the material deposited on the roadway on top of the knolls is hauled away by slips or wheelers, while the elevating grader is completing its round. A suitable adjustment of the working forces can be made so that the slips or wheelers can be kept up with the grader.

"On roads of Class 2, teams with dump-wagons follow the elevating grader, loading where cuts are to be made and dumping the materials in the fills, the elevating grader continuing its rounds and depositing directly on the road in the low places. Here again a suitable adjustment of working forces must be made so that the elevating grader will not have to wait on the wagons. It is more economical, however, to construct a mile or more of road at a time than it is to turn the elevating grader constantly, as would be necessary if each cut were completed by itself.

"On roads of Class 3, the elevating grader is simply used as a loader for the wagons, and each cut is completed by itself. The economy of the grader in this case depends upon the steepness of the grade and the room for maneuvering.

"As the elevating grader makes successive rounds it gets farther away from the center of the road and, consequently, when it is at the deepest part of the ditch where the heaviest cutting is being done the earth is deposited in the middle of the road, where the greatest filling is necessary to give the crown. The material deposited on the roadway will consist of many large lumps as well as of sods and fine material. To work this material down to a surface that can be traveled, the clods and sods must be broken up with a disk harrow until small enough to form a satisfactory surface. Often the sods and weeds are collected by harrowing with a stiff-tooth harrow and thrown out with pitchforks. To bring the surface to its final shape a few rounds must be made with a blade grader. Then, after the first rain, the surface is smoothed with a road drag and when partially dry, rolled. Constant dragging is necessary during the first year to keep the road in shape, while it is becoming compacted by traffic.

"Cost Data. The cost of constructing earth roads by this method varies from about $100 per mile for Class 1 roads, to $250 per mile for Class 2; while the cost of Class 3 is an exceedingly variable quantity, as is apparent from the nature of the work. As an average of the work done by some of the well organized counties $150 per mile may be taken. The cost of the elevating grader outfit is from $4000 to $5000, depending upon its size and the number of accessories used. To secure economical construction requires experienced supervision and proper working conditions, but when these are had, the use of the elevating grader is one of the most economical methods of earthroad construction. In general, it is not suitable for any unit smaller than a county, because of the cost of the outfit and the mileage of work which must be done yearly to make it pay."

Specifications of the Virginia State Highway Commission for soil roads are as follows: "Material to be used in surfacing the road is to be furnished by the county in beds, the contractor to throw out all stones over 3 in in diameter.

"The road-bed between the ditches shall be dressed to a reasonably true and uniform surface before the soil is applied.

"The contractor is to dig, cart and place upon the road in accordance with the specifications, the soil selected, and use no other. Should any other material be used, he is to remove same at his own expense. When directed by the Engineer, the contractor shall mix the soil with plow, disc and spike tooth harrows, or other satisfactory means until the surfacing material is of uniform texture. He will be paid for such work at the price per square yard set forth in the annexed proposal.

"The soil, when completed, shall be 10 in in thickness in the center, tapering to 3 in ...... feet from the center, except in cases where in the opinion of the Engineer in charge of the work these thicknesses should be increased or diminished. The surface roadway to be .... feet in width. Should any depressions appear, they are to be carefully filled with soil, so that the finished road will conform to the cross-section specified. The contractor shall maintain the roadway by use of a road machine, or other means satisfactory to the Engineer in charge of the work, true to the cross-section specified, until final acceptance as herein provided.

"All soil shall be placed as directed by the Engineer within 1000 ft haul and an allowance of 1 cent per cu yd per 100 ft will be made for overhaul in excess of 1000 ft. The contractor shall be paid by the cubic yard, measured on the road, deducting 33.3% when measured loose. Material measured after it has been thoroly wet, reshaped,

set and thoroly dry, in the opinion of the Engineer in charge of the work, and has been subjected to the ordinary traffic for 30 days, shall be termed compacted. It is optional with the Engineer in charge of the work as to whether material shall be measured loose or compacted."

10. Construction of Sand-Clay Roads

The general proposition of constructing sand-clay and topsoil roads has seemed so simple that the proper attention has not been given to the selection of materials and the construction work has not been done as thoroly as it should have been; consequently, many mixtures have been made and many natural soils used that have not given well surfaced roads, with the result that in many localities this type of surfaced road has been condemned. There is no reason why such errors should occur, as they can readily be avoided by a field examination of the soils, and when such results are at all doubtful, a laboratory test should follow which will give definite information regarding whether the material will or will not give good results when used for a road surfacing material. A great deal depends on the personal equation of the man in charge of the selecting of the road materials, and also on the personal equation of the man in charge of the construction work.

Drainage. The thoro drainage of a sand-clay or topsoil road is most essential. Where the subsoil is a sand it usually affords a satisfactory natural drainage, especially where there is considerable depth to the sand and usually the crown of the road is all the drainage required. It is necessary, however, in all cases that the water be taken out of the side ditches just as rapidly as possible, so that there will be no tendency for the water to seep back under the surfaced portion or to be drawn toward it by capillary attraction.

Location. It is very essential that a sand-clay or topsoil road should be so located that it can have at least several hours of sunshine on the surface of the road each day. If a road is located on the southern or western exposure of hillsides it will readily obtain a sufficient amount of sunshine unless the trees and brush are permitted to grow too close to the road. Care should be taken in every case that underbrush and trees are removed a sufficient distance to permit the sun's rays to strike the surface of the road and assist in quickly drying it out after a rain.

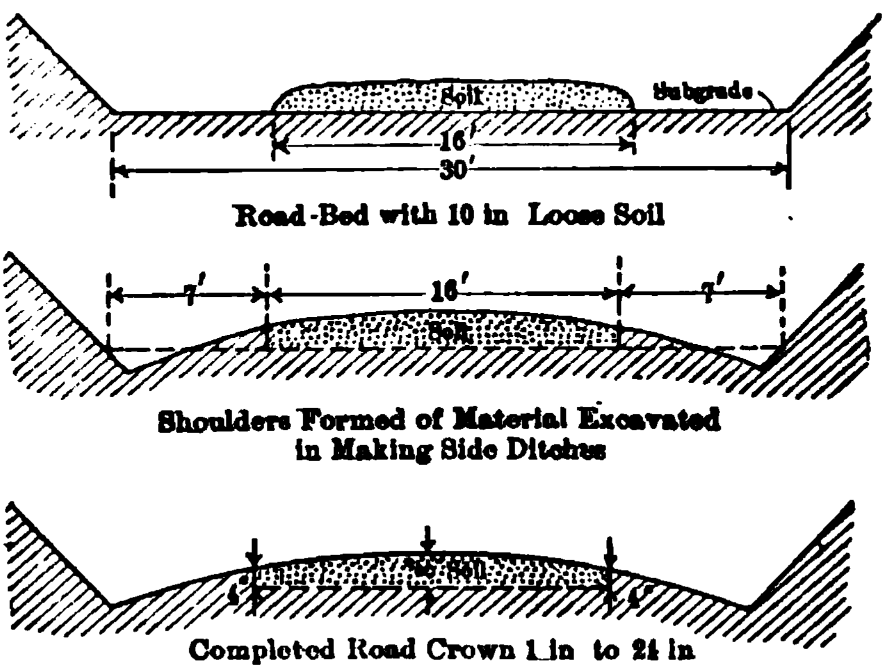

Fig. 3. Steps in Preparation of Soil Road

Surfacing with Topsoil. In preparing the grade to receive the topsoil surfacing material, it should be left practically flat and no ditch excavated. The topsoil should then be spread on the grade to a depth of 10 or 12 in in the center of the portion to be surfaced. If this is 16 ft wide, the surfacing material should be spread to a depth of at least 5 or 6 in on the outside of this width. This will compact to about two-thirds of the thickness of

the loose material. Thus the compact road would have a depth of 7 or 8 in in the center and 3½ to 4 in on the edges, which would make a crown of ½ in per ft. After the surfacing material has been laid, the ditches should be constructed and the material obtained from these should be thrown up to form the shoulders against the surfacing material.

As the surface compacts, it can readily be brought into shape with the drag, so that it has an even crown from the center of the road to the ditches. This method of construction is illustrated in Fig. 3. Whether the material excavated from the ditch will balance the fill, necessary to make the shoulder and give the right slope from this to the ditch, will depend upon the width of the surface portions and the total width of the road. Thus it may be necessary to borrow a certain amount of material to complete the fill; or to excavate the center of the road sufficiently to compensate the addition of the topsoil. This would be necessary where the grade has been made by side-hill cutting. This is illustrated in Fig. 4.

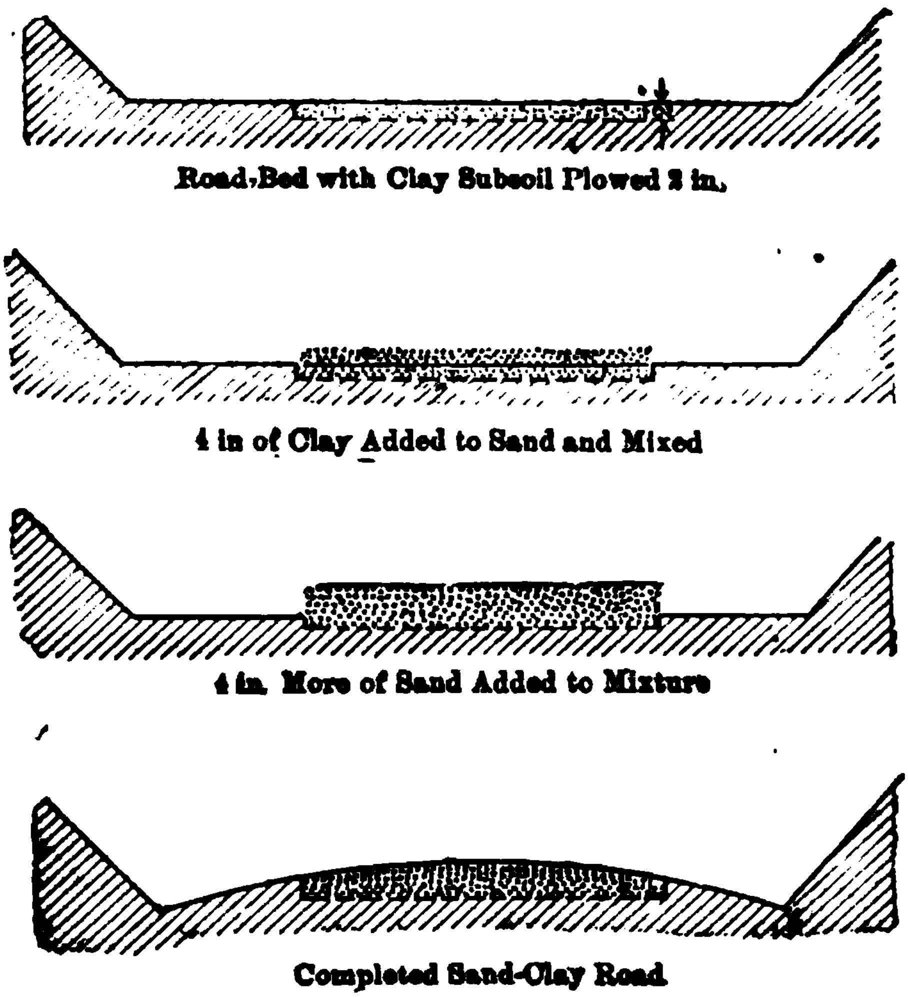

Fig. 4. Steps in Preparation of Sand-Clay Road

Many mistakes have been made in topsoil surfacing in trying to use too thin layers of surfacing material. Many such roads have been made where the topsoil has only been laid to a depth of 4 or 5 in, which, when it becomes compact, is only about 2½ to 3½ in thick. This is merely a crust over the subsoil and it is easily broken and cut thru, this being especially true when the traffic is at all heavy. All topsoil roads soften a little under excessive rain and this, according to the material used and method of construction, may extend to a depth of ½ in and occasionally 1 in; but, where the road has been constructed to a reasonable thickness, it is readily brought back into shape after a rain by means of the drag. If, however, the surfacing material is thin, it is very apt to break thru during excessive rains, and then the travel brings up the clay from the subsoil and the surfacing material is soon ruined. The thickness of the topsoil is partially dependent upon the character of the subsoil and, while 10 in is advocated as a general rule, it is desirable to increase the thickness even to 14 in when the subsoil is very micaceous or of a silty character.

Too much consideration cannot be given to the importance of depositing the topsoil on the road in such a manner that it will compact as one layer. This is absolutely necessary to obtain the best results. The required amount can perhaps be best deposited on the grade by means of a spreader. If this is not used and the topsoil is deposited on the road by means of

wheel scrapers, dump wagons, or otherwise, it should be immediately shovelled and raked into position, so that just as soon as travel begins to go over it the material will be compacted as one layer from the bottom upwards. The running of a plow thru the topsoil after it is spread and then harrowing it will benefit the resulting surface very materially, as it makes a more even, homogeneous layer and overcomes the uneven packing that otherwise would take place, due to the dumping of the topsoil on the road. It is necessary that it should be packed from the bottom upwards, for unless this is done a compact crust is formed on top, with loose material below, and there is a constant tendency for this crust to break thru and let water down into the soft material. The ordinary method that has been utilized to obtain this result has been the mixing and packing due to the hoofs of animals and the wheels of vehicles going over the road. This gives surprisingly good results, but it usually takes several months before the road is thoroly consolidated and packed. It is necessary while this packing is going on that after each rain the surface be immediately reshaped and crowned. This is necessary in order to avoid any hard lumps being formed, and ultimately to obtain a smooth, evenly crowned surface. The ordinary roller is practically worthless for compacting these roads. The desirable machine is one which will give similar action to the hoofs of animals and the tires of wheels. There is now on the market what is known as a sheep-foot or petrolithic roller which, it is reported, has been used successfully in California.

During the packing and consolidation of either a topsoil or an artificial mixture of sand and clay, it is a great advantage to have several rains follow almost immediately after the surfacing material has been placed on the road; for the puddling that results, due to the travel thru the deep mud, gives in the end a much denser packing as the road dries out and thus makes the surface itself much more durable and waterproof than when compacted under normal conditions. At such times, the road of course has the appearance of going all to pieces, but it is simply a step in the process of construction, which has to be gone thru either at one time or another, before the road will thoroly compact and become impervious to water. The clay cannot cement the grains of sand together until it has become thoroly wet and it is not sufficient to have the upper portion of the mixture wet but it must be wet from the top to the bottom of the mixed materials, otherwise a hard crust will be formed over loose material and the traffic will break thru it, making the surface rough and filled with holes. It is just as important to have all portions of the sand and clay thoroly wet and mixed before the mixture sets as it is to thoroly mix and wet a concrete mixture before permitting it to set.

Sand-Clay Roads on Clay Subsoil. Where it is impossible to obtain a natural mixture of sand and clay, it is practicable, in many cases, to make artificial mixtures that are economical and efficient. Conditions may exist where the subgrade is composed of clay which will make a suitable binder for sand, or it may be composed of sand to which clay should be added. Then, again, suitable sand and clay may occur within a reasonable distance so that it will be economical to haul these on to an earth base. It will be found that it is much easier to construct a sand-clay road when the subsoil is a suitable clay.

There are two ways of preparing the surface of the road with a clay subsoil before the addition of the sand. In one the road-bed is graded to practically the level of the ditch line; then that portion of the road to be

sanded is excavated to a sufficient depth so that the earth removed and placed along the shoulder of the road will give the right slope to the ditches, this being accomplished by means of the road machine and drag. The depth varies according to the width of the road and the depth of the sand-clay mixture. This will vary from 1½ to 3 in.

The clay subsoil is then plowed to a depth of 2 to 3 in, according to the character of the clay and of the sand. It should be plowed to a sufficient depth so that, when the clay plowed up is worked up and thoroly mixed with the added sand, it has been given a sufficient amount of clay to act as a binder. If the clay breaks up into too big clogs, these should be broken up with a disc harrow. Four inches of sand should then be added evenly over the surface and thoroly worked in with a disc harrow; then 4 in more sand should be added, and the harrowing repeated. The harrow in this last mixing can be so set as to work sufficient of the material toward the center to enable it to be readily dragged into shape, with the right crown (see Fig. 4).

If, after plowing the road surface to a depth of 2 to 3 in preparatory to putting on the sand, this clay is pulled out to the shoulder of the road, 4 in of sand is spread over the excavated portion of the road, 1½ in of the clay which was piled at the shoulder of the road is spread over this sand, and the two layers thoroly harrowed and then another 4-in layer of sand put on top of this mixture, and on top of this sand, a layer of clay 1 to 1½ in, and the layers thoroly plowed and harrowed, it will be found that even better results are obtained. This is a more expensive method, but the better results warrant such expense.

The road is now ready for a thoro wetting and the only practical method is to wait for a rain. A slight crust will form on the surface and it will appear as tho the clay was cementing the grains of sand together and making a firm road, but, after the first rain, traffic will break thru this since the mixed sand and clay beneath have not cemented but are loose particles. It is necessary that all parts of the sand-clay mixture should be thoroly wet, so that the mixture can be well puddled. Therefore, the best results are obtained if during the rain, the surface is harrowed, thus permitting the water to penetrate the lowest portions of the road.

After the rain, the road should be dragged into shape, when it will harden and set. It will also be found that during the thoro wetting of the surface a more complete and satisfactory mixture has been obtained, when the addition of the sand and clay has been made by the second method given above, for it is much easier to carry the clay down into the sand than it is to carry the sand into the clay.

Another method of preparing the subgrade for the sand-clay mixture is similar as in the topsoil road. It is left practically flat, with no ditch excavated. That portion of the road to be surfaced is then plowed to a depth of 1½ to 3 in, and the sand added, and the plowing and harrowing done as in the first method described above. After the sand-clay mixture has been made, the ditches should be constructed and the material obtained from these should be thrown up to form the shoulders against the sand-clay surfacing material, similarly as described for the topsoil road.

In many instances after the road-bed has been prepared for the sand, the total amount of sand is spread over the road and it is left for traffic to mix the clay and the sand together. This means that until there is a rain, there will be little or no mixing of the two materials and that traffic has to pull thru heavy, loose sand. Then, again, it takes a long time for

the traffic to thoroly mix the sand and clay together, and the final result is not nearly as good a mixture as by the method given above. The harrowing of the mixture during the rain is not essential, and this can, if desired, be left to traffic, but here again better results will be obtained if the harrowing is done. There is a tendency in constructing a sand-clay road in the manner outlined above to excavate to too great a depth the portion of the road to be surfaced, with the result that the finished road cannot be satisfactorily crowned. If the sand is hauled and placed alongside the road so that it can be added to the road during a rain, the harrowing can all be done at one time, and when the road has dried out and has been shaped up, it becomes a hard-surfaced road. The main objections to this method are that, unless there is sufficient rain to make the road extremely muddy and wet, the harrowing of the sand into the clay is apt to cause considerable of it to form round balls which are not broken up by the harrowing and thus there is not as even a mixture of the sand and clay as when they are mixed dry and then, later, harrowed when wet.

BURNT CLAY ROADS. In order to improve the roads in some parts of the Southern States where there is no sand, experimental sections have been constructed by burning the very plastic clay of which the roads are composed. The material is plowed up and is piled over a low cribwork of firewood. Alternate layers of wood and earth are built up until a height of about 3 ft is obtained. The length fired at any one time depends upon the number of men available. When the wood burns out the hardened clay is shaped up and compacted.

Sand-Clay Roads on Sand Subsoil. Road-beds with sand subsoils will be found principally in the Coastal Plain Regions where there is a minimum of grading in connection with the construction of the road. The sand road-bed should be left flat and a layer of clay spread over it as evenly as possible to a thickness of 2 to 4 in, according to the quality of clay and the amount of sand which it contains. If the clay used is a very pure plastic one, it will take a much smaller amount than if it is a very lean or sandy clay. There then should be spread over the clay a layer of clean sand and the road thoroly harrowed. Next, the road should be shaped up with the drag and left until it rains when it should again be harrowed similarly as described above. There is usually a tendency to use too much clay in making a sand-clay road where the sand is the subsoil. If the clay to be used is a very plastic one, there will be a tendency for it to ball and cake to such an extent that a plow can very often be used to advantage in breaking up the lumps. While the haulage charge for clay in making a sand-clay road on a sand subsoil is considerably less than the haulage charge for the sand in making a road on a clay subsoil, yet the cost of obtaining a thoro mixture of the clay on sand is much greater than of sand on clay. Then, again, the resultant road is not as apt to be as good, because the sand of the subsoil is not usually as sharp and coarse as can be obtained from creek bottoms when added to a clay subsoil.

While it is not possible to determine exactly the proportions of sand and clay to use, yet from experiments and analyses that should be made of the sand and clay, before utilizing them for road construction, the road mixture can be closely approximated. If there is too much clay, there will be a tendency for the surface of the road to become sticky or muddy in wet weather. This, however, can be remedied by spreading a thin layer of sand over the surface of the road. If the surface of the road loosens in dry weather, it is an indication that the clay used in the construction

of the road was not a good quality or there was not a sufficient amount of it. More clay should be added and worked into the road surface.

Sand-Clay Roads on Loam Base. Where the road-bed is composed of loam it will be necessary to haul both the sand and clay. The grade should be prepared as described in preparation for a topsoil surface. Four inches of sand should be first spread over the portion of the road to be surfaced and then 1½ to 3 in of clay spread evenly over the sand, the amount depending upon the quality of the clay, and these thoroly harrowed. Then 4 in more of sand should be spread evenly over the surface and harrowed. The balance of the work is the same as in the case of a topsoil road.

Construction Data. In Table IV there is given the quantity of clay and sand necessary to use per mile in making a sand-clay road. In these estimates the sand is supposed to be pure and the clay is supposed to be free from sand:

Table IV.—Cubic Yardage of Sand Clay and Topsoil

Width of Road Surfaced	Clay Subsoil		Sand Subsoil			
	Sand		Clay		Topsoil	
	8 in Deep	10 in Deep	1½ in Deep	3 in Deep	10 in Deep	12 in Deep
	Cu Yd	Cu Yd	Cu Yd	Cu Yd	Cu Yd	Cu Yd
9 Ft........	1173	1466	220	440	1466	1760
12 Ft........	1564	1954	293	586	1955	2346
16 Ft........	2085	2606	391	782	2606	3128

U. S. O. P. R. Specifications for Sand-Clay Roads (16) are as follows:

"**Subgrade.** The graded roadway shall be brought to the elevation, alignment, and cross-section indicated for subgrade on the plans, and shall be maintained free from ruts and other depressions until covered with the surfacing material.

"**Natural Sand-Clay Surfacing.** The engineer will designate suitable places for obtaining natural sand-clay mixtures for surfacing. All unsuitable material that may overlie the acceptable material shall be stripped off and removed, and this work will be paid for at the unit-price bid for stripping, measured in excavation. The natural sand-clay mixture shall then be excavated, hauled to the road, and spread. All excavation shall be so conducted that the pits will be left in good and sightly condition, and that, where possible, provision will be made for draining the pits without additional excavation beyond their limits.

"**Hauling.** The hauling shall be done in wagons of approximately uniform capacity, and the loads shall be dumped at such a distance apart as will give the amount of material required to construct the surface according to the proposed cross-section.

"**Spreading.** The surfacing material shall be immediately spread on the prepared subgrade to such depth that the surface, when compacted will conform accurately with the profile, alignment, and cross-section, as shown on the drawings. All subsequent loads may then be hauled over the surface thus formed. The construction of the surface shall begin at that point on the road nearest the source of material and be continued from such point. In hauling over the material as deposited, wagons will be required to use the entire width of surfaced roadway so as to compact the whole section as nearly to a uniform density as possible. The teams will not be permitted to follow a single track or to form ruts.

"**Finishing.** After 500 or 600 ft of roadway have been thus roughly constructed the surface shall be cut up and pulverized to a depth of 2 or 3 in with a plow or harrow and at the same time the shoulders on each side of the surfaced portion of the road shall, if necessary, be sufficiently loosened to permit of a smooth regular crown being

constructed from shoulder to center of road. When the roadway has been loosened sufficiently, the surface shall be worked with a road grader or drag to the true cross-section required by the plans. This operation shall be repeated daily until the entire surface becomes smooth and firm.

"**Mixing Sand-Clay.** In case the natural sand-clay mixture, as found, does not contain a sufficient percentage of either sand or clay to give a durable surface there shall be spread as much of the deficient material as the engineer may direct, and this shall be thoroly mixed and incorporated with the material previously spread. In places where a natural mixture is not available suitable amounts of clay or sand shall be hauled, spread, and mixed as directed by the engineer. The process of mixing may require plowing to a depth of 6 or 8 in and harrowing with a disc or tooth harrow, and this work may be required in wet weather. All mixing shall be classed as extra work and shall be paid for at prices bid for force account work. The completed surface will be paid for by the cubic yard of surfacing material used, measured in excavation. So much of the surfacing material as is necessarily hauled more than ...... feet will be classed as sand-clay overhaul and paid for at the price bid for this item."

Maine State Highway Commission Specifications for Sand-Clay Roads are as follows:

"**Materials.** Sand and clay shall be furnished by the contractor from sources approved by the engineer. Sand shall be composed of hard, sharp, angular particles, at least 50% of the volume of which, by dry weight, shall be retained on a 50-mesh sieve. Rounded grains of sand will not be accepted. If plastic clay is used it shall be placed upon the road in pieces not larger than 3 in in size. Slaking clay shall be placed in pieces not larger than 6 in in size.

"**Method of Construction.** The road shall first be brought to subgrade in accordance with the foregoing specifications and as shown by the typical sections.

"Sand Subsoil. Wherever the subsoil is sand, 6 in of clay shall be uniformly spread over the surface to a width of 16 ft, unless otherwise directed by the engineer. Each load of clay should be spread uniformly as soon as deposited and before being driven over. Immediately after the clay is spread it should be covered with a layer of clean sand 6 in in depth unless otherwise directed by the engineer, and shall then be deeply plowed with a heavy plow until all lumps are thoroly broken up and the clay and sand are thoroly mixed to a depth of 14 to 16 in as directed by the engineer.

"Clay Subsoil. Wherever the subsoil is clay, 8 in of sand shall be uniformly spread over the surface to a width of 16 ft unless otherwise directed by the engineer, and on this layer of sand 4 in of clay shall be uniformly spread and then deeply plowed with a heavy plow as above specified to a depth of 14 to 16 in as directed by the engineer.

"**General.** The proportions of clay or of sand or both may be varied from time to time if, in the opinion of the engineer, better results can be obtained thereby, but in any case the mixture shall then be thoroly puddled with a sufficient quantity or water and alternate plowing and harrowing with a disc-harrow until a thoro mixing and puddling have been obtained. If, after plowing and harrowing, the mixture has a tendency to cake or ball more sand must be added and on the other hand if the mixture after drying tends to loosen and separate, more clay must be added. The engineer shall decide whenever such additions of materials are necessary. The road shall then be shaped with a road machine, or other similar implement, crowned, smoothed and allowed to dry; then it shall be again shaped and smoothed to the satisfaction of the engineer and covered with a light course of sand.

"**Payment.** Sand-clay surface will be paid for per cubic yard in accordance with the typical section showing a width of 16 ft and a depth of 8 in or 10.7 cu ft per lin ft of road on the assumption that the quantities of sand and clay above specified will, in place, be equivalent to a depth of 8 in."

Cost Data. The main item of cost in surfacing a road with topsoil or sand-clay is the charge for haulage. This cost depends upon the proximity to the road of the materials to be used in surfacing. According to this distance and the width of the road surface, such roads have been surfaced at a cost of $250 to $2500 per mile. Even at this latter figure these roads are economical. Table V gives construction and cost data for several sand-clay roads constructed by the U. S. O. P. R. (16).

Table V.—Cost of Sand-Clay Roads, Exclusive of Grading and Materials

Construction Items	Location of Roads							
	Brookville, Fla.	Moscow, Miss.	Pearsall, Tex.	San Antonio, Tex.	Gay Head, Mass.	Jackson, N. C.	Tarboro, N. C.	Sayre, Okla.
Length surfaced in miles	0.45	0.78	0.79	1.00	2.19	0.45	2.50	0.75
Width of graded road in feet:								
Cuts	28	30	26	40	22	30	22	28
Fills	20	30	26	26	22	30	22	28
Width surfacing in feet	16	17	15	16	16	14	18	14
Sand mixture:								
Sand in cubic yards	660	1524	......	......	1700	......	......	......
Distance hauled in miles	0.75	1.5	......	......	0.125	1.00	......	......
Depth applied in inches	3	......	......	......	6	7	......	......
Clay mixture:								
Clay in cubic yards	830	......	1556	1825	2300	890	2815	1388
Distance hauled in miles	0.50	......	0.19	0.057	0.10	1.00	......	1.42
Depth applied in inches	7	......	8	7	6	......	6	8
Scale of wages per hr:								
Laborers	$0.1750	$0.100	$0.1200	$0.1500	$0.200	$0.125	$0.0800	$0.160
Teams	0.5000	0.250	0.3000	0.3450	0.500	0.350	0.2400	0.300
Cost:								
Subgrade, per square yard	0.0310	0.003	0.0064	0.0088	......	0.002	0.0018	0.007
Stripping for surfacing material per cubic yard	......	......	0.0910	0.0720	0.010	0.029	0.0050	0.134
Hauling sand, per cubic yard	0.4250	0.490	......	......	0.223	0.840	......	......
Hauling clay, per cubic yard	0.3740	......	0.9140	0.2860	0.344	......	0.2550	0.567
Spreading material, per cubic yard	0.0190	0.007	0.0320	......	0.003	0.077	0.0178	0.072
Mixing sand and clay, per square yard	0.0035	0.006	0.0017	0.0069	0.010	......	0.0024	0.007
Final shaping, per square yard	0.0035	......	0.0005	0.0015	0.004	0.002	0.0022	......
General expense, per square yard	0.0157	......	0.0030	......	0.006	0.003	0.0007	......
Total cost, per square yard	$0.198	$0.105	$0.121	$0.089	$0.082	$0.233	$0.036	$0.187

MAINTENANCE

11. Maintenance of Earth Roads

The surface of an earth road should be kept free of dirt, and whenever any holes or ruts have developed in the road they should not be filled up with stone or brush, but with earth, and with earth as nearly as possible of the same character as that composing the surface of the balance of the road. If, on the other hand, holes or ruts are filled with rock, gravel, or brush, the wearing effect will be uneven, and the wheels will begin to scoop and

cut out holes just beyond or on the opposite side of the road from the hole filled up. If there are stumps or rocks in the road, they should all be removed, so that the earth surface can be smoothed over and brought to an even slope from the center to the ditches.

As the road drag is the principal machine that will be used in the maintenance of an earth road, it is absolutely necessary that the rocks and stumps be removed or else the drag cannot be used. If the drag is used regularly after every rain just as the roadway is drying out, the surface can be kept smooth and hard the greater part of the year.

As moisture is very detrimental to an earth road, the sun should be permitted to strike the surface of such road as much as possible, care being taken not to have too much shade. Where necessary the trees should be cut away so that the whole surface of the road is exposed to the sun for at least several hours during the day. Shade is good for a macadam road, but too much shade is bad for an earth road. This does not mean that all trees alongside of an earth road should be cut, thus destroying to a large extent the beauty of the highway, but it does mean that sufficient trees should be cut so that there will be no part of the road surface but what will be exposed to the sun for a part of the day. The removal of the trees also permits ready access of air and wind along the road that very materially assist in evaporating the water and drying the road.

In repairing an earth road the same thought must be given as in its construction, and, when cleaning out ditches, the material should not be thrown into the middle of the road or on any part of the surface of the road, but it should be thrown into the adjoining fields, for this material is usually composed largely of fine silt and organic matter, which holds moisture like a sponge and becomes very difficult to dry out, and is entirely different in character and consistency from the earth surface of the road.

In the maintenance of earth roads, they should be divided into sections, with a foreman or overseer in charge of each section, whose duties should be to go over every mile of the section after every rain and at least every 2 weeks, and to have, when portions of the road are worn or disintegrated, repairs made at once. After each heavy rain a road drag should be run over the road in order to bring it into shape, and to fill up any ruts or holes that might have been started.

Oiling of Earth Roads in California (10). "By 1906 there were very few sections of oiled road that were satisfactory for the traveling public and only in a few localities could the oiled earth road be called a success. The publication of many articles, reports and bulletins favorable in their criticism of this construction has given the oiled earth roads of California an unmerited reputation as to their length of satisfactory service, their simplicity of construction and their adaptability to all sorts of soils, weather conditions and character of traffic. Very likely the greater portion of the oiled earth roads that have become very objectionable to the traveling public, due to their wavy surface, have been constructed with an excessive amount of oil. Road surfaces that are overoiled are not firm under traffic and there is generally a tendency for the surface material to slowly flow to lower elevations. The shoulders of such roads, after a few months, show a very deep thickness of wavy, somewhat spongy oiled earth and the crown of the road is protected by an oil surfacing that is rapidly ironed out by traffic and becomes so thin that it breaks under traffic. Once the surface is cut thru to the underlying soil base, a bad chuck hole is rapidly formed. Thruout the valley and coast counties of California there are miles of oiled earth roads that are so objectionable to the traffic that the traveled way is on the sides of the road and not at all on the oiled section. The failures of oiled earth roads may be due to one or more of many mistakes, the more common ones being the use of too much oil per square yard of road surface, the lack of properly incorporating the oil in the road surface, and the use of an oil not suited to the work.

"The California Highway Commission has made but little use of this type of road construction. In a few places in the state where the road had very deep fills it has been inadvisable to build a concrete pavement until the fills have had sufficient time to settle thoroly. In such cases the road surface has been wet and rolled and then the surface of the road broken up for a depth of about 1 in and a coat of light asphaltic oil applied. This was regarded only as a temporary expedient to protect the road surface from excessive cutting during the heavy rains of winter and as a dust preventive during the dry months.

"There were used on this construction oils varying in specific viscosity, Engler test, from 5 to 15. The oil contained from 75 to 90% of 80 penetration asphalt. The oil was applied on the road under pressure and at a temperature of about 121° C (250° F). A very light oil also has been used which contained from 30 to 60% of asphalt of 80 penetration. This oil was applied by gravity at the rate of 1.5 gal per sq yd."

Oiling of Earth Roads in Illinois (20b). "Roads should not be oiled until they have a permanently established grade; that is, all hills should be cut down, hollows filled, embankments widened, and all drainage structures established. Low, flat, undrained roads should not be oiled until proper drainage has been attended to. The oiling of a mudhole will not remedy the trouble but often aggravates it. Roads that have a preponderance of heavy hauling should not be selected for oiling. The oiling tends to waterproof the road, but it is readily understood that continued heavy hauling even on perfectly dry earth roads will eventually rut and dig them out in pot holes. The mixture of oil and earth lacks stability to meet all the requirements of traffic. If something could be mixed with the oil and earth to give it stability and aid it to resist the wear of traffic, it would more nearly meet all traffic conditions. On moderately traveled roads where there is a greater amount of pleasure travel, the oiled earth roads will give better service.

"The Road Surface Preparatory to Oiling. As the prime objects of oiling an earth road are the suppression of the dust and the maintaining of a smooth waterproof surface, it is very important that the road surface be oiled when it is smooth, free from dust, and in a condition to absorb the oil. Oil applied on dust will not penetrate the road surface, but will merely mix with the loose material to make an oiled-dust surface that is apt to fly readily and become a nuisance. The surface should be perfectly smooth and free from low places that will retain water. If water is allowed to stand upon an oiled earth surface, a bad mud hole will soon result. A moist subsoil preparatory to oiling is not serious tho best results may be expected when the road is reasonably dry for about 2 in on the surface.

"Cost of Surface Oiling. The cost of preparing a road for an oil treatment may vary from $100 to $2000 per mile. However, the grading and preparation of an earth road should not be charged against the cost of oiling. The oiling or dragging of an earth road is a maintenance proposition and should be estimated separately from the building or preparing of the road. The road should be kept well shaped regardless of whether it is to be oiled or not. However, some cleaning is almost always necessary prior to the first application of oil, and this cost will vary from $25 to $50 per mile of road. Road oil can be purchased for from 3 to 7 cents per gal, depending upon the quality. It may be applied on the surface of the road at the rate of ¼ to ½ gal per sq yd. So the cost of oil alone may vary from $75 to $275 per mile of road 15 ft wide, depending upon the quality and quantity of oil applied. The cost of applying the oil will vary depending upon the length of haul and the kind of equipment used. This cost may be estimated at from $50 to $150 per mile of road 15 ft wide. The above figures show the cost of oiling to vary from $150 to $475 per mile of road. With average conditions and with a medium priced oil, the average cost of oiling alone per application may be from $200 to $250 per mile of road 15 ft wide. It must be understood that these costs are based on the conditions prevailing during the season of 1915. In view of all the information that is available on oiled earth roads, indications are that the treatments must be made each year or at least every other year to get the desired results. On this basis, $150 to $200 per year for 5 to 10 years may be a basis for estimating the cost of surface oiling."

Illinois Specifications for Surface Oiling Earth Roads are as follows:

"Preparation of Earth Road Surface. The earth road surface shall be smooth, free from sod, vegetation, loose material or other foreign matter and shall conform to the cross-section shown on the plans. It shall be compacted with a tractor or a

power roller that weighs at least 300 lb per in of width of tread of one wheel; and the compacted surface shall be smooth and free from waves. The surface shall also be free from dust and sufficiently dry to prevent the wheels of the oil distributor from sticking or marring the surface. If the surface of the road is rutted in any manner or is dug out into holes or depressions that would retain water, it shall be made perfectly smooth by dragging at suitable times prior to the application of the oil.

"APPLICATION OF OIL. Oil shall not be applied upon the road until after the surface has been approved by the engineer. The oil shall be distributed uniformly over the width of road specified. It shall be applied by a pressure distributer under not less than 15 lb pressure per sq in. The distributor shall be regulated so that the width to be oiled shall be covered by one, two or more equal strips without overlapping. Extreme care shall be taken to get the oil uniformly distributed. All places not covered by the first application of oil shall be covered by hand-pouring cans which shall follow immediately behind the distributer. The oil shall be applied in at least two applications. The total quantity of oils used shall be not less than ½ gal per sq yd of surface specified to be oiled. Whether applied in two applications or more, the amount of oil for each application shall be the same, and there shall be a period of at least 6 hr intervening between successive applications or such additional time as is necessary for the oil to be absorbed and offer no tendency to stick to the wheels. From the time of the first application of oil until 3 days after the last application, the road shall be kept closed to all public travel. Oil applied on days having an air temperature of less than 24° C (75° F), and oil that is too heavy to penetrate readily into the surface of the road, shall be heated to the temperature prescribed by the engineer before applying same.

"TESTING OIL. No oil shall be used until after having been tested and approved by the engineer. All oil used shall comply with the following specifications:

1. The oil shall be a fluid product, free from water.

2. Specific Gravity. Its specific gravity at 25° C (77° F) shall not be less than 0.890 (28.3° B).

3. Total Bitumen. It shall be soluble in chemically pure cold carbon disulphide to the extent of at least 99.5%.

4. Viscosity. When 240 cc of the oil is heated in an Engler Viscosimeter to 50° C (122° F) and maintained at this temperature for 5 min, the first 50 cc which flows thru the aperture shall show a specific viscosity of not less than 5.0 nor more than 20.0.

5. Residue on Evaporation. When 30 g of the oil, in a tin dish 2½ in in diameter and ¾ in deep with vertical sides, is evaporated until a residue of a penetration at 25° C (77° F) of 10 mm is obtained when tested with Dow machine, No. 2 needle, 100 g, 5 sec, the weight of the residue shall be at least 40% of the weight of the oil taken for evaporation. At no time during this evaporation shall the oil be heated at a temperature to exceed 250° C (482° F)."

12. Maintenance of Sand-Clay Roads

The success and efficiency of the sand-clay and topsoil road is practically dependent upon systematic maintenance which consists largely in the systematic use of the road drag, particularly after every heavy rain. In maintaining the sand-clay or topsoil road no material should ever be dragged from the ditches on to the surfaced portions, for all such scrapings usually contain more or less organic matter which will cause the road to disintegrate and ultimately destroy it. Ditches, after they have once been brought into the right grade, should be disturbed as little as possible. Wherever possible, grass should be permitted to grow from the ditches to the surfaced portion of the road. The mowing of the grass is one item of the cost of maintenance.

Provision must be made ahead of time for obtaining suitable material with which to add to a topsoil road whenever it becomes necessary to fill up any depressions or holes that have been formed and which are too large to be remedied by the drag. The material used should be of the same character and quality as the original topsoil. If necessary, such materials

should be purchased ahead of time at various points along the road, so that the road supervisor would know where he can obtain suitable material with which to make his repairs.

In adding material to a sand-clay surface, the sand and clay, of approximately the same character as the original surface, should be thoroly mixed together and tamped into the holes and then the surface dragged. If, however, the drag has been consistently used on the road from the time it was built, it will only be very rarely that holes will develop that have to be filled in this way. When, however, it does become necessary to fill ruts and holes with topsoil or sand-clay mixtures or to add these materials to the surface of the road, it is absolutely necessary that the holes should be cleaned of all dead material, and the bottom loosened before any new material is added. It is also just as important that the surface of the road should be swept clean of loose, dead material and harrowed with a spiked tooth harrow before adding a layer of the new material; otherwise, the new material will not become firmly attached and incorporated with the old material.

The Patrol System of Maintenance is, perhaps, more necessary in maintaining the sand-clay road to its highest efficiency than most any other form of surfaced road. The following general instructions (32) are suggested for patrolmen:

1. Inspect the road for its entire length during a rainy day and locate all holes, which will be easily noted as they will be filled with water.

2. Use the road drag immediately after a rain.

3. Fill all holes and depressions that cannot be evened up with the drag with good material, and then go over the section again with a drag.

4. Never put on the road any sod, sand or any material from the side ditches. Obtain fresh material of the same character as the balance of the road.

5. When the road surface is very rough, run a spiked tooth harrow over it while the road is still wet and this will very materially increase the efficiency of the drag.

6. In dragging the road, drag from the edges of the surfaced portion of the road toward the center. Be careful never to drag any material from the unsurfaced portion of the road on to the surfaced part.

7. Be sure after dragging the road that no ridge has been left between any portion of the road and the ditch. At times a one-horse cultivator can be used to advantage in removing the ridge that may have formed between the wheel rut and the ditch. The drag should be used immediately afterwards to bring the surface of the road back into shape.

8. Remove all glass, tin cans, nails and rubbish of whatever character that may be found on the surface of the roadway.

9. See that all culverts are clear, with outlets and inlets in good order, and that the water can run freely in the ditches.

10. The old surface of the road must be cleaned and roughened before new material is added.

Dust Preventives and Binders for Sand-Clay and Topsoil Roads. But little experimental work has thus far been done in regard to utilizing various oils, asphalts and other products as binders or dust preventives in connection with sand-clay or topsoil roads. Glutrin gives good results as a dust preventive and very favorable results have been obtained from the application of glutrin to sand-clay roads as a binder. This result is not obtained until several months to a year after the application of the glutrin.

Light and medium asphaltic oils have been experimented with to a limited extent and give indication of being satisfactory as dust preventives and binders. The application of these materials, even as dust preventives, will increase the life of the sand-clay or topsoil road.

Cost of Maintenance. The cost of maintaining sand-clay and topsoil roads, as outlined above, varies from $50 to $100 per mile per year, according to the width of the road. These figures represent the maintenance of a road constructed as described above. Reports are made that such roads have been maintained at a cost of $10 to $30 per mile per year, but this does not mean the thoro, systematic maintenance advocated above. In some instances a road with a 9 ft surface of sand-clay has been maintained satisfactorily at $30 per mile per year.

13. Road Dragging

Methods Recommended by the U. S. O. P. R. (31). "The principal factor in successfully operating a properly constructed road drag, provided that the condition of the road is favorable, is skill on the part of the operator. Under ordinary circumstances the position of the hitching link on the draw chain should be such that the runners will make an angle of from 60° to 75° with the center line of the road, or in other words, a skew angle of from 15° to 30°. It is apparent that by shifting the position of the hitching link the angle of skew may be increased or diminished as the conditions require. When dragging immediately over ruts or down the center of the road after the sides have been dragged, it is usually preferable to have the hitching link at the center of the chain and to run the drag without skew. When the principal purpose of the dragging is to increase the crown of the road, they should be sufficiently skewed to discharge all material as rapidly as it is collected on the runners. On the other hand, if depressions occur in the road surface the skew may perhaps be advantageously reduced to a minimum, thus enabling the operator to deposit the material which collects in front of the runners at such points as he desires by lifting or otherwise manipulating the drag. The length of hitch is another very important consideration in operating the road drag. It is impracticable to prescribe even an approximate rule for fixing the length of hitch, because it is materially affected by the height of the team and the arrangement of the harness, as well as by the condition of the road surface. Experience will soon teach the operator, however, when to shorten the hitch in order to lessen the amount of cutting done by the front runner and when to lengthen it in order to produce the opposite effect. When the road surface is sufficiently hard or the amount of material which it is desired to have the drag move is sufficient to warrant the operator standing upon the drag while it is in operation he can greatly facilitate its work by shifting his weight at proper times. For example, if it is desired to have the drag discharge more rapidly, the operator should move toward the discharge end of the runners. This will cause the ditch end of the runners to swing forward and thus increase the skew angle of the drag. The operator may, of course, produce the opposite effect by moving his weight in the opposite direction. In the same way, he can partially control the amount of cutting which the drag does by shifting his weight backward or forward, as the case may be.

"When to Use the Drag. It is fully as important that a road be dragged at the right time as it is that the dragging be properly done. The rule frequently cited, that all earth roads should be dragged immediately after every rain, is in many cases entirely impracticable and is also very mis-

leading because of the conditions which it fails to contemplate. It is true that there are many road surfaces composed of earth or earthy material which do not become very muddy under traffic, even during long rainy seasons, and since such surfaces usually tend to harden very rapidly as soon as the weather clears up, it may be desirable to drag roads of this kind immediately after a rain. Such roads, however, would not ordinarily need to be dragged after every rain, because of the strong tendency that they naturally possess of holding their shape. On the other hand, many varieties of clay and soil tend to become very muddy under only light traffic after very moderate rains, and it is evident that roads constructed of such materials could not always be successfully dragged immediately after a rain. Sometimes, in fact, it may be necessary to wait until several consecutive clear days have elapsed after a long rainy spell before the road is sufficiently dried out to keep ruts from forming almost as rapidly as they can be filled by dragging. In many cases of this kind, however, it is possible greatly to improve the power of the road to resist the destructive action of traffic during rainy seasons by repeatedly dragging it at the proper time. Well constructed sand-clay and topsoil roads should not often become muddy after they are once well compacted. They may become seriously rutted, how-

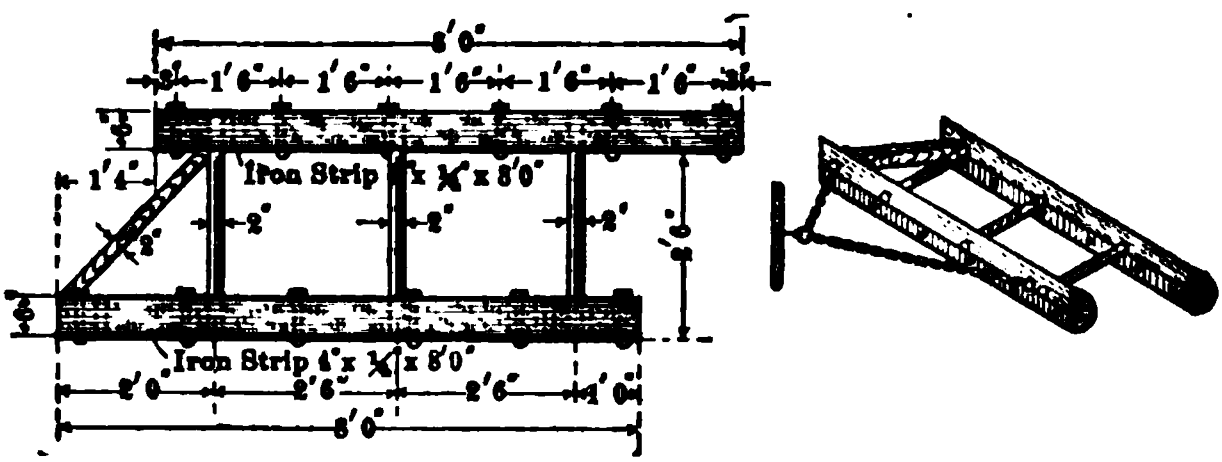

Fig. 5. Standard Split-Log Drag of Penn. State Highway Dept.

ever, under heavy traffic, during rainy weather, and are almost sure to need dragging several times each year. Such roads should ordinarily be dragged as soon after a rain as practicable, as otherwise the surface soon becomes dry and hard, so that it is necessary to do considerably more dragging in order to fill the ruts. Furthermore, the material which the drag moves will not compact readily unless it contains a considerable amount of moisture. In general, it may be said that the best time to drag any type of road is when the material composing the surface contains sufficient moisture to compact readily after it has been moved by the drag and is not sufficiently wet for the traffic following the drag to produce mud."

"**Split-Log Drag** (19b). The best material for a drag is dry red cedar. Red elm and walnut when thoroly dried are excellent, and soft maple or even willow are preferable to oak, hickory or ash. The log should be 7 or 8 ft long and from 10 to 12 in in diameter, and carefully split or sawed down the middle. The heaviest and best slab should be selected for the front. Set the halves flat sides to the front, fasten 30 in apart inside measure with 3 strong stakes, the ends of which are wedged in two 2-inch auger holes, bored thru the slabs. Both slabs are the same length but the rear one should extend 14 or 16 in away from the ditch end of the front slab as indicated in Fig. 5. A platform of 1-in boards should be built to lay on top of the slabs to enable the driver to walk all over the drag quickly and securely. To fasten the chains, simply wrap one end around an end stake, carry it over the top of the slab, out to the double trees and then back to the ditch end of the slab, where it should be slipped thru a

bored hole and can be fastened by slipping a bolt thru one of the links. The hole should be bored 3 or 4 in from the end of the slab and about its center up and down. A strip of iron 3 or 4 in wide, and ½ in thick should be attached to the front slab. It is not necessary to have this iron over 40 to 42 in long, but the life of the slab will be prolonged if it is extended the entire length of the slab. The iron should be attached so that it will be ½ in below the lower edge of the slab at the ditch end while the other end should be flush with the slab. The bolts holding the plate in place should have flat heads and the holes to receive them should be countersunk. If the face of the log stands plumb, it is well to wedge out the lower edge of the blade with a three-cornered stop of wood. Two common mistakes are made in constructing a drag, one is in

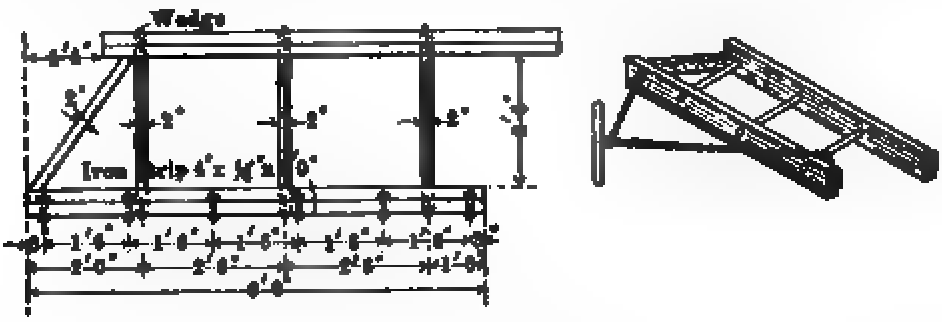

Fig. 6. Standard Plank Drag of Penn. State Highway Dept.

making it too heavy. It should be so light that one man can easily lift it. A light drag responds more readily to the various methods of hitching and to the shifting of the position of the operator. If desired a drag may be made heavier at any time by proper weighting. The other mistake is in the use of squared timbers with too wide a face on the ground, instead of those with sharp edges, whereby the cutting effect of the sharp edges is lost and the drag is permitted to slide over instead of to equalize the irregularities in the surface of the road.

"Plank Drag (19b). Drags may be made of planks instead of logs. In some localities logs of suitable size are hard to obtain and for this reason plank drags are coming into general use. Elm and cypress are perhaps the best wood to use but if these are not obtainable, something strong and light will do. The plank should be

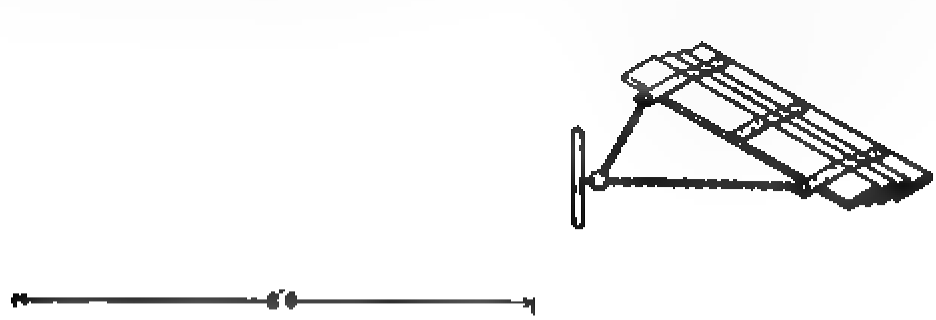

Fig. 7. Standard Lap-Plank Drag of Penn. State Highway Dept.

7 or 8 ft long and 2 by 12 in in section, reinforced lengthwise of its center by a 2 by 6-in plank. The other details (see Fig. 6) are the same as for a split-log drag.

"Lap-Plank Drag (19b). Another form of home-made drag that is used quite often, is what is called the lap-plank drag (see Fig. 7). This form of drag is particularly useful where the soil is a sticky clay that is hard to work, when it is wet, with the split-log or plank drag. It will move but a very small quantity of earth, however, and its principle value is to puddle the road and smooth the surface when the ruts and holes are not deep. This drag is usually made of planks about 9 ft in length, 12 in wide and 1 in thick. They may be bolted together or bound with iron straps at each end and in the middle, the straps being placed about 1 ft from each end. The planks are lapped one on top of the other, usually three, the top one being the forward

one. Each plank is lapped over the underlying one about 6 in. The iron straps are from 4 to 6 in wide, and the end ones, to which a chain is fastened, extend about 2 in beyond the front edge of the drag. These ends have holes drilled in them for attaching the chain.

"Steel Drags (19b). While the wood drags are more generally used, yet all of the road machine companies are now manufacturing all steel drags and these can be obtained at reasonable prices."

Illinois Road Drag Law. The General Assembly of the State of Illinois, in 1908, passed a Road Drag Law authorizing the road commissioners in any township to have earth roads dragged at all seasons of the year whenever it was deemed to be beneficial, and to contract with the adjoining land owners for this work at a rate of from 75 cents to $1 per mile, not less than 20 ft wide, for each time the road was dragged, the higher price to be paid for work done during the months of Dec., Jan., Feb., or March. The law also provides it to be unlawful to place loose earth, weeds, sods, or other vegetable matter on a road which has been dragged without the authority of the road officials; to place any material which will prevent the free flow of water; for any traffic to pass over a surface just dragged until same shall have partially dried out or have frozen, except in those instances where the road is not sufficiently wide to provide a safe by-pass or on roads wide enough so that the wheels will not make a rut nearer than 9 ft to the center of the dragged portion. In order that all commissioners should follow the same practice, the following instructions were published (13a):

"Roads properly dragged will dry out weeks earlier in the spring than a road not so maintained, and when dried out will be smooth and in excellent condition. Moreover, they will not rut up so readily during the winter. The ordinary country road can be well maintained if dragged at the proper time on an average of twice a month. The dragging will have to be more frequent during winter and spring than in summer. Unless the road is in the right condition, the work of dragging will be wasted. One thing to be insisted upon is that the work be done at the right moment. The right time is when the road is wet. The muddier it is the better the results. On a road that is in extremely bad condition where the mud is very deep, it is probable that the lap-plank drag can be worked to better advantage. In the summer time and in the early fall, dragging should be done while it is actually raining, for unless the rain is exceptionally heavy and long continued, the water will penetrate the dry roadbed so fast that the surface will be comparatively dry when the drag is used after the rain has stopped, with the result that the road surface will work up in crumbs. When this happens it is a sign the road is too dry. The nearer it is possible to spread the mud over the road as a mortar, much in the same way a mason works mortar with a trowel, the greater the improvement produced. Under no conditions should a road be dragged when it is dry. This merely crumbles up the surface and makes a layer of the loose material which quickly becomes dust and, when wet, is turned into mud and holds the water on the surface of the road. Drag when the road is good and muddy. Don't drag when it is dry. Drag whenever possible at all seasons of the year. If a road is dragged immediately before cold weather, it will freeze in a smooth condition."

Kansas County Road Drag Contract. "This Contract, made this ....day of ...., 191..., between the Board of County Commissioners for...................................County, Kansas, party of the first part, and...party of the second part;

"Witnesseth; 1. That said second party hereby contracts and agrees to drag and care for the section of County Road hereinafter described, from this date to.......... ...., 191..., said road being known as Section............of Division ....of County Road No.........., and covering as follows: Beginning at........................and ending at........................., or a total length of............miles.

2. If at any time second party is unable to drag this section when it is necessary, he agrees to procure a substitute who will perform the service for said second party.

3. Second party agrees to drag this section, or so much of it as can be dragged, at such times and in such manner required by the County Engineer.

4. That he will keep himself informed, by actual view or otherwise, of the condition of this section of road, and report any damage to culverts, bridges, or grade, promptly to the County Engineer.

5. It is agreed, that for the services rendered under this contract, the County Commissioners will pay said second party the following, in full compensation: For each round trip with drag, as per the County Engineer's instructions, ...per mile, being............for each round trip over entire section. For repairing culverts or bridges, or any other service rendered on County Engineer's orders, ...per hour for single hand, and ....per hour for man and team. Second party to make on his voucher for such services, under oath, and present same in same manner as other claims against the county.

6. This contract will be annulled, and of no effect upon the failure of the second party to fulfill the contract, and he hereby agrees upon notice of such failure, to return to the County Engineer, the county property in his charge and surrender this contract immediately.

Witness our hands, this..............day of...................., 191....

The Board of County Commissioners.

By........................County Engineer.

................................Contractor."

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SECTION 10

GRAVEL ROADS

BY

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STATE HIGHWAY COMMISSIONER OF CONNECTICUT

GENERAL DATA

1. Historical Development

The first roads were built of local material without regard to durability or suitability for road purposes, but as the travel developed, it became imperative to secure materials better than the local material and still of easy access. The next step, therefore, after the earth road was the gravel road, and evidences of gravel roads are found in antiquity, proving that the logical development of transportation was first from the earth to the gravel and so on. Samples of gravel roads are found in Rome and Great Britain. The Roman roads were probably built by slaves and captives of the Cæsars and the British roads by the Britons under duress by their own conquerors.

2. Characteristics

Adaptability. There are millions of miles of rural highways at the present time which are not improved and which, when constructed, will have roadways of local materials. At the same time, there is an enormous need for an improvement in the general condition of all rural roads, and there are few communities or localities where suitable material may not be found

convenient for the improvement of these highways. By far the most universal of these common materials is gravel secured either from banks or from the beds of streams. The location is easily found. The material is cheap in first cost and easily handled. The general results of proper gravel construction are more satisfactory and economical than those secured from any other known natural material. By its very composition, gravel is suitable for a road surface, the material having been formed primarily by the washing or wearing away of the rough corners of small particles of rock in such a manner as to preserve the most durable particles which, therefore, will take a considerable amount of abrasive wear without rapid disintegration. By the same method of formation, the material has generally been so mixed that the percentage of voids is comparatively low, and hence, by the addition of a small amount of cheap binding material, a practically impervious surface can be secured with a minimum amount of manipulation.

Characteristics. A gravel road constructed by any one of the followings mentioned methods has several notable peculiar characteristics which do not pertain to roads of other types unless they are of extremely high grade. A gravel road is easily repaired. The material for repairs is locally available and of the same character as the material of which the road was originally built. Such a road is fully as durable, if not more so, than a crushed stone road unless the stone which has been crushed is of an extremely hard and tough texture with a high coefficient of wear. The gravel road is comfortable to ride upon, whether at a slow or fast speed, due probably to the almost imperceptible shifting of the particles which go to make up the road itself. The road is easy of traction and is not as dusty without treatment as an earth road or a road built of crushed stone. Without bituminous treatment, it cannot be considered as adaptable to traffic exceeding 100 motor vehicles per day and can only be considered safe and adaptable for such traffic in good weather, as during certain months of the year, it will be practically impassable for motor travel. Again, as the travel increases, the cost of maintenance will increase to a point when it may be demonstrated that it would be cheaper to build a more permanent type of roadway. Climatic conditions have much influence on the characteristics of a gravel road. For instance, the objection to a gravel road on account of adverse frost conditions is largely eliminated in a mild climate. Nevertheless, a gravel road has its limitations, but can be used more universally and requires less technical supervision than any other known type of construction.

3. Drainage, Foundations and Subgrade

The ordinary rules, which apply to the drainage and foundation of highways, are applicable to gravel roads except that greater care should be taken in the preparation of the foundation and subgrade and the proper drainage of the road than with more durable types if the road is to be given continuous use. However, carelessness in the preparation of foundation and subgrade will not result as disastrously in the case of gravel roads as in the case of a road of more expensive type since the cost of reconstruction is materially less. Generally speaking, the subgrade should be free from projecting stones, stumps and pockets of vegetable material, should be firmly rolled, and shaped in such a manner as to afford a proper foundation for the gravel surface. The drainage both beneath and on the sides of the road should be carefully designed so as to give continuous service and the structures of sufficient magnitude to remove all danger of washouts, up-

heavals due to frost, and other ills which may result from improper drainage design.

4. Crowns

For gravel roads which are to be treated with bituminous carpets, the cross-crown on the road, except on grades, should not exceed ⅜ in per ft. For roads which are to be treated with some other method or left untreated, the cross-crown should not exceed ¾ in per ft with the exception of grades, where the cross-crown should be sufficient to allow the water to run laterally off the surface of the road without causing longitudinal ruts.

MATERIALS

5. Occurrence of Gravels

Definitions. Bank gravel is defined by Committee D-4, Am. Soc. Test. Mat. as "gravel found in natural deposits, usually more or less intermixed with sand, clay, etc; gravelly clay, gravelly sand, clayey gravel and sandy gravel indicate the varying proportions of the admixture of the finer materials." Unless otherwise stated, the word gravel will hereafter be used to designate bank gravel.

There is another type of gravel which is not ordinarily suitable for road construction, namely, river, lake or sea beach gravel. This class may be defined as gravel consisting of round or oval stones with regular smooth surfaces, containing no binding material such as sand, silt or clay.

Formations. Gravel, as noted in the definition, is found in banks, in the beds of rivers or on the shores of large bodies of water. The generally accepted theory of the existence of gravel deposits is that the gravel was deposited during the glacial period of the earth's geologic history, when so-called terminal moraines were formed. The relative sizes of the particles going to make up the bank gravel were supposedly determined by the relative agitation of the water in which the particles of stone were suspended. The gravel located near the beds of rivers or on the shores of lakes or seas was and is still formed by the constant attrition of particles of broken rock one upon the other, these particles being agitated in the water either by the wind, tides or currents. See Sect. 3.

Distribution. The precise location of gravel banks is largely a matter of careful, skillful search. Banks may be located by a practiced observer, however, by simple methods. In what is known as a gravel country, that is where the material is prevalent, the better quality is sometimes found in low, round mounds, and the character of the gravel may easily be determined by the digging of test pits. In a country in which gravel is not generally prevalent, the location of gravel banks may be indicated by a combined growth of white birch and small pine trees, which growth almost invariably indicates the presence of gravel of some class or another, but generally of a good quality. Gravel may be also found, as noted, in the beds of streams or on the banks of lakes, and if the geologic history of a section of country is known, indications of gravel may be secured by studying the different formations and the possible previous location and path of glaciers.

6. Physical Properties of Gravels

Composition and Characteristics of Different Gravels. In the first place, it may be said that no two gravels are likely to have the same composition and characteristics. Consequently, it is difficult to draw a specification

for the material to be used in a gravel road within very narrow limits. Nevertheless, there are certain prime requisites which are necessary in all gravel, which may be used for satisfactory gravel construction.

The composition and laboratory tests of gravels from Iroquois Beach, Lake Ontario, Canada as given by Reinecke (25) are as follows:

Location	Clay	Lime Carbonate	Estimated Percentage in the Gravel Portion of: Limestone Pebbles	Hard Pebbles, Granites, Traps, etc.	Soft Pebbles, Shales, Schists, Sandstones, etc.	Percentage of Loss by Abrasion Test	French Coefficient of Wear	Cementing Value Fin[e] Aggregate Under ¼ I[n.]
Lot 8.	None	None	85	10	5	[illegible]	13.2	34
Lot 23..	None	Moderate amount	90 to 95	[illegible]	Small	2.7	14.7	66
Pit 117.	None	Abundant	70	20	10	2.5	16.1	[illegible]
Pit 143..	5 to 10%	Present with clay	50	Rare	50	7.5	5.4	89
Pit 144	Small amount	Abundant	50	25	25	3.7	11.0	72

Agg (5b) describes the composition of Iowa gravels as follows: "The fact that Iowa gravels do not contain as great a percentage as is desirable in material to be used for road surfacing is shown by the following results of the analysis of 151 samples of gravel which were obtained from practically every county in the state that has any gravel.

"Seventy-eight samples contained less than 25% of material that was retained on the ¼-in screen.

"Thirty-eight samples contained less than 35% and more than 25% of material that was retained on the ¼-in screen.

"Nineteen samples contained less than 50% and more than 35% of material that was retained on the ¼-in screen.

"Sixteen samples contained an excess of 50% of material that was retained on a ¼-in screen. This last named group includes all of the gravels that are really coarse enough for high grade gravel surfacing, but since such a small percent of Iowa gravels are of this class, it is necessary to adapt the construction methods to the use of the poorer gravels.

"In general Iowa gravels do not contain sufficient clay to serve as a permanent binder and yet the gravels do bind in time, showing that some other element in the gravel is a factor in the bonding action. The variation in clay content and the comparatively small amount of clay the materials contain are shown by the following results of the analysis of the 151 samples mentioned above:

107 samples contain less than 6% of clay;
32 samples contain less than 11% of clay but more than 6%;
8 samples contain less than 16% of clay but more than 11%;
4 samples contain more than 16% of clay."

Requisites of Good Gravel. Gravel for road building purposes should generally consist of material formed from hard stone particles which will resist abrasion. It should contain of these stone particles at least 75% of pebbles ranging in size from ¼ to 1½ or 2 in. Stone particles above 2 in in size are too large to use in the construction of gravel roads unless they

be built in courses. The gravel should, in addition, contain about 25% of a sand or clay mixture, of which from 8 to 15% should be clay or similar binding material, such as oxide of iron or limestone. Naturally, there are few gravel banks which will fulfill all the requirements mentioned without either the addition or removal of some material. Generally speaking, most gravels contain either too many large stones or too large a proportion of fine sand. A gravel bank which contains gravel in proper proportions for road building is extremely rare. On the other hand, many gravel banks exist which, by the addition of material easily secured locally, will give excellent results when used for road building purposes. The proportion of binding material required depends mainly on the type of road to be constructed as discussed in Art. 10.

Durability. As mentioned above, the stone pebbles which go to make up the gravel should be of hard and tough character. Many gravel banks, otherwise suitable for road work, fail in that the stone particles crumble up under the abrasion of metal tires and become dust so soon that the gravel road easily wears out.

Binder. As noted above, gravel should contain from 8 to 15% of cementing material, such as clay, limestone or iron oxide. One of the best binders for gravel is clay and the amount of clay content to be included in road building gravel varies considerably, and should vary not only with the character of the material going to make up the gravel but also with the climatic conditions under which the material is used. In cold and wet countries, a smaller amount of clay should be used, since the tendency of clay is to make mud. In warmer and dryer climates, an additional amount of clay should be used, as here the amount of moisture is less and there is a greater need for binder and less danger of mud therefrom. The bond of the gravel road is entirely chemical; that is, there is no mechanical bond between the particles since they are round and will easily roll one upon the other. Consequently, some chemical bond must be secured which can be obtained by the use of clay or other cementing material which has a chemical action on the particles. There are many proprietary substances sold for the purpose of binding gravel roads. These substances are referred to in Art. 17. In connection with the binder for gravel, it is sometimes the custom to add loam to the gravel for binding purposes. The use of loam is poor practice unless nothing else can be secured. There are few localities, however, where either stone chips or clay may not be secured so that the use of loam is hardly excusable.

7. Sampling and Tests of Gravels

Sampling Gravel from Pits, Stream Beds, Etc. In order to make the proper laboratory tests on gravel, it is necessary to take samples of local material in such a manner that the test will indicate, so far as is possible, a relation between the sample and the entire bank. Consequently great care should be taken in securing samples of gravel to take such material as will indicate the general character of the bank, having in mind the proportions and different sizes as they exist, together with the character of the material which goes to make up the pebbles and also the finer material. In this connection, it might be wise to add a sample from other sources which would indicate the character of binding material which might be found in the same locality and which might be added to the existing gravel to give successful results. In connection with the testing of gravel, it may be well to state that for many banks an inspection of the gravel and local roads

built from it will give a very fair indication of the value of the material for road making purposes, but the different tests, as outlined below, will supplement the practical knowledge gained by observation and give actual results as to the resistance of the gravel to abrasion and its suitability as indicated by the different operations and tests thru which the gravel is required to pass.

The following method for sampling gravel was adopted at the first conference of State Highway Testing Engineers and Chemists, called by the U. S. O. P. R. in Feb., 1917.

"By Whom Taken: Samples are to be taken by the engineer or his authorized representative.

"When Taken: Samples are to be taken from the proposed source of supply at least ...... days before the gravel is to be accepted or rejected, also from every ...... cu yd excavated, or when the quality or appearance of the gravel changes, and at such other times as may be directed by the engineer.

"Where and How Taken: (1) Sampling at the pit. Enough samples shall be taken to represent an average of the material. An individual sample must be taken thru a full vertical section of that material which it is proposed to use at the point selected. Each sample shall be taken from a freshly exposed vertical face. (2) Sampling from cars, barges, etc. Enough samples shall be taken, as directed by the engineer, to represent average composition. Samples from cars shall be taken from both ends and from top and bottom of the car.

"Amount and Size of Sample: (1) Sampling for quality: Sample shall weigh, for screened gravel, 25 to 30 lb; for bank gravel, 50 to 75 lb. (2) Sampling for size. A sample for size shall weigh not less than 10 lb for materials of ¾ in maximum diameter or less. Samples of materials of other sizes shall increase in weight to a maximum of approximately 60 lb, varying with the size and weight of the largest pieces represented by the sample. The sample shall be representative of the product as delivered for use.

"Marking and Shipping: Samples shall be shipped in tight boxes or bags and shall be accompanied by a card in the container or securely attached thereto, stating date, by whom taken, by whom submitted, source of supply, exact location where sample was taken, proposed purpose to which the material is to be put, space for remarks, and, in case of pit or bank investigation, owner, quantity available, amount and character of stripping, whether material from same source has been previously used, where and for what purpose, and with what results, haul to nearest point on road, average haul to job, character of haul, initial cost of work."

The Methods of Testing Gravels given herewith are those adopted by the Special Committee on "Materials for Road Construction" of the Am. Soc. C. E., designated Am. Soc. C. E. Method, those proposed by Committee D-4, "Standard Tests for Road Materials" of the Am. Soc. Test. Mat., designated Am. Soc. Test. Mat. Com. D-4 Method, and those adopted at the first conference of State Highway Testing Engineers and Chemists called by the U. S. O. P. R. in Feb., 1917.

Mechanical Analysis of Broken Stone, Broken Slag or Gravel. Am. Soc. Test. Mat. Com. D-4 Method. "The method shall consist of, first, drying at not more than 110° C (230° F) to a constant weight a sample weighing in pounds six times the diameter in inches of the largest holes required; second, passing the sample thru such of the following sized screens having circular openings as are required or called for by the specification,

screens to be used in the order named: 8.89 cm (3.5 in), 7.62 cm (3 in), 6.35 cm (2.5 in), 5.08 cm (2 in), 3.81 cm (1.5 in), 3.18 cm (1.25 in), 2.54 cm (1 in), 1.90 cm (0.75 in), 1.27 cm (0.5 in), and 0.64 cm (0.25 in); third, determining the percentage by weight retained on each screen; fourth, recording the mechanical analysis in the following manner:

Percentage passing 0.64-cm (¼-in) screen.............. =
Percentage passing 1.27-cm (½-in) screen and retained on 0.64-cm (¼-in) screen.............................. =
Percentage passing 1.90-cm (¾-in) screen and retained on 1.27-cm (½-in) screen.............................. =
Percentage passing 2.54-cm (1-in) screen and retained on 1.90-cm (¾-in) screen.............................. =
.... =

100.00"

Mechanical Analysis of Sand or Other Fine Highway Material. (See Sect. 17, Art. 4).

Mechanical Analysis of Mixtures of Sand or Other Fine Highway Material with Broken Stone, Broken Slag, or Gravel. Am. Soc. C. E. Method. "The method shall consist of: (1) Drying at not more than 110° C (230° F) to a constant weight, a sample weighing in pounds six times the diameter in inches of the largest holes required; (2) separating the sample by the use of a 10-mesh sieve (Am. Soc. Test. Mat. standard sieve); (3) examining the portion retained on the 10-mesh sieve in accordance with the method for making a 'Mechanical Analysis of Broken Stone, Broken Slag, or Gravel'; (4) examining the portion passing the 10-mesh sieve in accordance with the method for making a 'Mechanical Analysis of Sand or Other Fine Highway Material'; (5) recording the mechanical analysis in the following manner:

Percentage passing 200-mesh sieve.................. =
Percentage passing 100-mesh sieve and retained on 200-mesh sieve.................................. =
Percentage passing 80-mesh sieve and retained on 100-mesh sieve.................................. =
.... =
Percentage passing 10-mesh sieve and retained on 20-mesh sieve.................................. =
Percentage passing 0.64-cm (¼-in) screen and retained on 10-mesh sieve............................ =
Percentage passing 1.27-cm (½-in) screen and retained on 0.64-cm (¼-in) screen...................... =
Percentage passing 1.90-cm (¾-in) screen and retained on 1.27-cm (½-in) screen...................... =
.... =

100.00"

Voids in Mineral Aggregates. Am. Soc. Test. Mat. Com. D-4 Method. "The voids in mineral aggregates shall be determined by the Cone Specific Gravity Method. In the method of making the determination of voids, as hereinafter described, there shall be used a truncated cone made of No. 18 B. & S. gage galvanized steel with calked seams and having the following dimensions: overall diameter of bottom, 25.4 cm (10 in); overall height, 25.4

cm (10 in); inside diameter of opening, 7.6 cm (3 in). The test shall be made in the following manner: First, thoroly mix the aggregate by rolling on paper; second, fill the cone with aggregate avoiding segregation; third, compact aggregate in cone by oscillation on edge of cone resting on wooden floor, wooden box, or block of wood, and use cotton waste pressed against surface of aggregate to prevent segregation during oscillation; fourth, continue to add aggregate and compact until the cone is full of thoroly compacted aggregate, which process will require from 300 to 500 oscillations; fifth, weigh cone with aggregate; sixth, weigh cone empty; seventh, weigh cone full of clean water; eighth, determine the specific gravity of aggregate; ninth, the percentage of voids in the aggregate shall be calculated by the following formula:

$$\text{PERCENTAGE OF VOIDS} = \left\{1 - \frac{C - A}{(B - A)\,D}\right\} 100$$

in which A represents the weight in grams of the cone; B, the weight in grams of the cone filled with water; C, the weight in grams of the cone filled with compacted aggregate; D, the specific gravity of the aggregate."

Abrasion Test for Gravel. Am. Soc. C. E. Method. "The test for abrasion of gravel shall be made with a Deval abrasion machine. (For description of machine, see Sect. 11, TESTS FOR BROKEN STONE). A charge of gravel shall consist of pieces which shall pass a screen having circular openings 5.08 cm (2 in) in diameter and be retained on a screen having circular openings 1.27 cm (0.5) in diameter. The total weight of gravel in a charge shall be within 10 g of 5 kg (11.02 lb). The gravel to compose a charge shall be washed, and dried in a closed oven for 1 hr at a temperature within 5° of 110° C (230° F). The charge of gravel shall be placed in one cylinder of the machine, which shall be rotated at a rate of not less than 30 nor more than 33 rev per min. Ten thousand revolutions shall constitute a test. The percentage of material worn off which will pass thru a sieve having openings of 0.16 cm (0.06 in) shall be considered the amount of wear of the charge of gravel. The loss by abrasion, determined as stated, shall be expressed in terms of the percentage of the total weight of the charge of gravel."

Method adopted at first conference of State Highway Testing Engineers and Chemists. "The aggregate is first screened thru screens having circular openings 2 in, 1 in, and ½ in in diameter. The sizes used for this test are equally divided between those passing the 2-in and retained on the 1-in screen, and those passing the 1-in and retained on the ½-in screen. The material of these sizes is washed and dried. The following weights of the dried stone are then taken: 2500 g of the size passing the 2-in and retained on the 1-in screen, and 2500 g of the size passing the 1-in and retained on the ½-in screen. This material is placed in the cast-iron cylinder of the Deval machine as specified for the standard abrasion on stone. Briefly described, this machine consists of a frame and two or more cylinders mounted at an angle of 30° with the axis of rotation. The cylinders are of the following size: 20 cm diameter by 34 cm deep, inside dimensions. Six cast-iron spheres, 1.875 in in diameter and weighing approximately 0.95 lb each, are placed in the cylinder as an abrasive charge. The iron composing these spheres, which are the same as those used in the Standard Paving Brick Rattler Test, has the following limits of composition: Combined carbon, not under 2.50%; graphite carbon, not over 0.25%; silicon, not over 1.00%; manganese, not over 0.50%; phosphorus, not over 0.25%; sulphur, not over 0.08%.

"After the cast-iron spheres have been placed in the cylinder, the lid is bolted on and the cylinder mounted in the frame of the Deval machine. The duration of the test and the rate of rotation are the same as specified for the standard test for stone, namely, 10 000 revolutions at a rate of 30 to 33 rev per min. At the completion of the test the material is taken out and screened thru a No. 16 mesh screen. The material retained upon the screen is washed and dried and the percent loss by abrasion of the material passing the No. 16 screen calculated.

" When the material has a specific gravity below 2.20, a total weight of 4000 g instead of 5000 g shall be used in the abrasion test."

Cementation Test for Gravel Powders. See Sect. 11, Art. 5.

Elutriation Test for Silt. Method adopted at first conference of State Highway Testing Engineers and Chemists. " The entire sample is moistened and thoroly mixed and a sample weighing approximately 105 g* is obtained for elutriation and grading by quartering or by selecting small portions from various parts of a flat pile. The sample is then dried at not over 110° C (230° F). This dried sample is accurately weighed and placed in a 500 cc* beaker, and about 350 cc* of water is added and agitated in such manner that no whirling results. After settling for 20 sec the water is poured off thru a 200-mesh sieve, and the operation of agitation, sedimentation and decantation repeated until the wash water is approximately clear. Particles caught on the 200-mesh sieve are then washed back into the washed sample remaining in the beaker. The entire washed sample is dried to constant weight, and accurately weighed, and the

$$\text{PERCENT BY ELUTRIATION} = \frac{\text{ORIGINAL WEIGHT} - \text{FINAL WEIGHT}}{\text{ORIGINAL WEIGHT}}."$$

8. Specifications for Gravels

The following specifications for gravels were adopted at the first conference of State Highway Testing Engineers and Chemists called by the U. S. O. P. R. in Feb. 1917.

" General. The gravel shall be composed of hard, durable rock, of high resistance to abrasion, together with sand and clay or other binding material, and shall be free from thin or elongated pieces.

" Grading for Base Course. (1) The gravel, when tested by means of laboratory screens, shall meet the following requirements: Passing a .... in screen, 100%; total retained on ¼-in screen, ...% to ....%. (2) The material retained on the ¼-in screen is known as coarse aggregate. The coarse aggregate, when tested by means of a laboratory screen, shall meet the following requirement: Total retained on .... in screen, ...% to ....%. (3) The material passing the ¼-in screen is known as fine aggregate. The fine aggregate, when tested by means of a laboratory sieve, shall meet the following requirement: Total passing 200-mesh sieve, ...% to ....%.

" Grading for Wearing Course. (1) The gravel when tested by means of laboratory screens, shall meet the following requirements: Passing a .... in screen, 100%; total retained on ¼-in screen, ...% to ....%. (2) The material retained on the ¼-in screen is known as coarse aggregate. The coarse aggregate, when tested by means of a laboratory screen, shall

*If the sand is so coarse that a 100-g sample is not sufficient, the size of the sample, the container, and the amount of water used, may be proportionally increased.

meet the following requirement: Total retained on .... in screen, ...% ....%. (3) The material passing the ¼-in screen is known as fine aggregate. The fine aggregate, when tested by means of laboratory sieve, shall meet the following requirement: Total passing 200-mesh sieve, ...% to ....%."

Am. Soc. Mun. Imp. specifications for gravel. See Art. 14.

Can. Soc. C. E. specifications for gravel adopted in 1917 are as follows:

"Definition. Gravel shall consist of naturally formed fragments of tough, durable rock, well graded in size from the smallest to the largest, free from flat, elongated particles, and shall not contain more than 15% by weight of soft, friable material. It shall not contain an excess of clay nor an excess of loose or adhering dust, vegetable loam or other deleterious matter. It shall be satisfactory to the engineer in all respects.

"Screened Gravel. Screened gravel is gravel fulfilling the above requirements which is screened into one or more of the sizes defined in the Specifications for Crushed Stone. See (10) and Sect. 11, Art. 7.

"Run of bank gravel is gravel fulfilling the requirements of these specifications, which shall be classed under one of three grades shown below according to qualities determined in a properly equipped laboratory. The properties determined shall be the coefficient of wear and the proportions of the various sizes of particles present.

"The coefficient of wear shall be determined on material passing a screen having circular openings 2 in in diameter and retained by a screen having circular openings ½ in in diameter. The test shall be conducted in the same manner as that for determining the coefficient of wear of crushed stone. Run of bank gravel shall be classed according to the following grades:

"Grade A is a run of bank gravel containing a large percentage of pebbles of igneous rocks. It shall not contain more than 5% by weight of material which shall be retained on a screen having 4 in circular openings, and not more than 45% by weight of material which shall pass a screen having ¼ in square openings. It shall not contain more than 3% by weight of clay or loam nor have a coefficient of wear of less than 14.

"Grade B is a run of bank gravel containing a smaller percentage of igneous rock pebbles. It shall not contain more than 5% by weight of material which is retained by a screen having 4 in circular openings nor more than 60% by weight of material retained by a screen having ¼ in square openings. It shall not contain more than 9% by weight of clay or loam nor have a coefficient of wear of less than 11.

"Grade C is a run of bank gravel composed chiefly of pebbles of sedimentary rock. It shall not contain more than 5% by weight of material which is retained on a screen having 4 in circular openings, and not more than 80% by weight of material which passes a screen having ¼ in square openings. It shall not contain more than 12% by weight of clay or loam nor have a coefficient of wear of less than 7.

"Grade D is a run of bank gravel which does not meet the requirements of any of the above grades and which may be used only by written permission of the engineer.

"When so directed by the engineer, gravel shall be crushed. The material so produced shall conform to the requirements of screened gravel or run of bank gravel as directed by the engineer."

9. Excavating, Screening and Hauling Gravel

Excavation. There are many methods of excavating gravel from the pit, each of which has its use for particular local conditions. The height of the bank, whether above or below the ordinary ground level, or whether easily accessible from the highway; all these factors enter into the methods of excavation. Ordinarily, for pits which are above the road over which the material is to be hauled to the work, gravity can be employed in handling the material; while for pits below the surface, some mechanical method of elevation should be employed if the job is of sufficient magnitude. If the job is of small extent, the gravel may be excavated, screened and loaded by hand. If a job is of greater extent, the material may be handled by a steam shovel loading directly into the carts or directly into the screens

as outlined below. Convenient area, in the vicinity for the waste material which may not be used, should be supplied so that the excavated material, which is of no use, can be easily disposed of without obstructing the economical operation of the gravel bank.

Care of Gravel Pits in Winter. Recommendations by the Iowa State Highway Commission (15c). "Cover the surface with a heavy coat of straw. This will keep out the frost and will save much dynamite. Open up the runway, on an easy grade, at the south side of the gravel pit, so that the sun will help with its heat. Back down the runway and load so that the pit is circular and as soon as possible drive into the pit and make a circuit in coming out. Keep the bank caved down from the top, throwing all black dirt and frozen chunks out. Always load from the bottom and clean up as you go. Keep pushing back the straw as it is necessary to uncover for more material. Cave down the last thing at night and remove all frozen chunks toward the center which cannot be used for road material. Be sure that the walls of the pit are entirely covered with loose material when left for the night or over Sunday."

Screening. As suggested in Art. 4, there are few gravel banks, which contain material of a proper quality, without screening or the addition of other materials, for the construction of a gravel road. For the ordinary gravel road, built with comparatively little care for light travel, the necessity for grading material is sometimes roughly covered by simply raking or shovelling out the larger sized stones; but for roads built with any degree of care for moderately heavy travel, or for roads which are to be treated either with a bituminous surface or with a dust palliative, considerable care should be taken in separating different sizes of material.

There are many methods of screening gravel, and that one used will depend upon the location of the pit and the character of material contained therein. The screening of gravel in almost any pit is in itself a local problem, but there are numerous devices for the proper handling and screening of gravel which will bear mentioning.

With the HAND screen, the material is thrown by hand against an inclined screen of different sized mesh and the different sized particles are separated thereby. This screen is ordinarily used for separating the fine sand and stones from the gravel, leaving the larger particles for use in the road. This method can best be used where a small quantity of gravel is to be secured either for road repairs or for the surfacing of short sections. It is however evident, in this day of high-priced labor, that the use of mechanical means for handling large volumes of gravel or other material is of extreme value. Consequently the use of hand screening should not be seriously considered for work of any magnitude.

MECHANICAL means for screening gravel are many and varied, but may be roughly divided in two classes: first, for removing fine or coarse material, and, second, for separating the different sizes of aggregate. Both types usually consist of an elevator and screens operated by power. The screen for removing the fine particles consists of a single screen of a mesh of approximately ½ in square agitated by a rotary cam. This screen allows the fine material passing thru the screen to fall into a pile to be used either for sand or for top dressing the road, and the coarse material is shot from the lower end of the screen, which is set on an incline, into a bin or into the waiting wagon. The use of bins is advised simply because it obviates the necessity of wagons standing still while the screens are loaded. Screens for separating the gravel into different sized particles consist of an elevator and rotary screen similar to those used on portable crushing plants. In these plants, the gravel is elevated and passed thru the screen and the particles which are too large for road construction purposes are removed

and placed in the waste heap. Such apparatus may be combined with an excavator or drag line bucket for loading the elevator so that the use of hand labor is reduced to a minimum. The use of graded screens will give far better results for the construction of roads where considerable care is to be taken in the first construction of the road or where the bank gravel does not approximate a satisfactory mixture for road construction purposes.

Crushing and Screening. Certain pits contain so much large material that it is economical to crush and screen the gravel at the same time. In other words, the entire output of the bank is passed thru a crusher so that the larger particles are crushed small enough for road construction purposes, and the entire mass passed thru a screen and into storage bins. Where extensive road building is to be carried on, this method gives excellent results, because: First, the entire output of the bank is used and waste piles are not necessary; second, the resultant material gives a better road than ordinary gravel.

It should be borne in mind in excavating and screening gravel for road construction purposes that a considerable amount of the material should be screened and piled alongside the road for maintenance purposes after the road is constructed. When gravel must be excavated and hauled for short distances either to a crushing plant or screens, single horses and carts may be employed with one driver to at least three carts.

Crushing and Screening Plants for road gravels as used in Wisconsin are described as follows by Donaghey (13): In many eastern and southern counties of Wisconsin there are numerous gravel pits of excellent quality, but usually containing a rather high percentage of large stone, and many containing an excess of binder. To handle this particular kind of gravel economically and get the very best results, it is necessary to crush and screen it. An ordinary portable jaw crusher with screen and bins is used, having a capacity of from 80 to 120 cu yd per day, usually equipped with conveyor and grizzly screen which removes the fine material and transfers it to the elevator, allowing only the coarse stone to pass thru the crusher jaws, which increases the capacity from 20 to 40%. The crushers are equipped with a three-compartment portable bin, with 35 to 50-cu yd capacity, and a two-section screen, each section 30 in in diameter and 4 ft in length; the first, or lead section, having 1½-in perforations; and the second section 1¾-in perforations, which separates the material into three sizes. The No. 1 size consists of material refusing the 1¾-in ring; the No. 2 size the material refusing the ½-in ring and passing thru the 1¾-in ring; the No. 3 size, the material passing thru the ½-in ring. The crusher jaws are adjusted so as to produce about equal proportions of the No. 1 and No. 2 sizes.

In many instances better results are obtained by crushing the gravel fine enough for practically all the material to pass thru the 1¾-in ring, and to carry over, into the No. 2 material, just enough of the No. 3 or bonding material to fill the voids in the No. 2. This is accomplished by placing a sheet-iron jacket around the lower three-fourths of the first section of the screen, which does not permit all of the finer material to pass thru the ½-in perforations, but carries over, into the bin with the No. 2 material, the necessary binder. This must be regulated so as to just fill the voids in the No. 2 material with the No. 3, and no more. The balance of the No. 3 material will naturally drop into the No. 3 bin and may be used in finishing the surface where additional binder is required, or for future maintenance and other purposes.

Hauling. In general, the cost of gravel road construction may be reduced the most by refinement in methods of hauling the material. Consequently every possible effort should be made to reduce the cost of hauling gravel to the lowest possible point. Hence it may be said that the gravel bank should be so equipped that the time of loading in the pit should be a minimum and the time of unloading at the job should also be small. This gives rise to the necessity on large construction jobs for some method of quickly loading wagons or vehicles which transport the gravel, while

the vehicles themselves should be easily and quickly dumped at the job. With this end in view, the construction of bins for the storage of gravel so that the vehicles may be loaded by gravity is advised where the size of the job will warrant it. It is fairly easy to devise a satisfactory manner of excavation and screening from one of the above mentioned methods, but the proper determination of the hauling devices is one of considerable difficulty. Four general methods will be described: First, the use of teams; second, traction engines and trains; third, motor trucks with or without trailers; and fourth, industrial railroads. In connection with all of the four methods, it must be understood that considerable money may be spent on the road entering the gravel pit in order that larger loads may be hauled with greater ease of traction.

Team Hauling. For hauls up to 1 mile or on small jobs, the use of teams is advised and beyond that distance, the determination of the method of hauling depends greatly on local conditions. The teams to be selected for hauling the gravel should be composed of strong, active, seasoned animals, either horses or mules, and properly designed wagons. The amount of load will naturally be determined by the grades to be surmounted and the character of the road surface over which the load is to be hauled. Ordinarily, a team of two good horses can haul about 1.7 yd for a mile economically. The wagons to be employed should be of strong and rugged construction, easily dumped. The use of tail dump wagons is not advised. In some instances, the old-fashioned slab-bottom brick wagon can be used to good advantage, where a part of the load is to be dumped and the remainder carried to another point. For road construction purposes, where all the material is to be used and deposited in piles, the use of bottom dumping wagons properly constructed is the best practice. The wheels of the wagon should be large and the tires broad. The wagons should be constructed so as to be easily turned. Care should be taken during the construction of the road to see that the wagons are kept in good condition, well-greased and free from liability of breakdowns. Extras for parts liable to breakage should be kept at hand.

Traction Engine and Train. Where the length of haul exceeds a mile and where the material can be secured in large quantities quickly and conveniently and where the job is of sufficient magnitude to justify the expenditure of money for special equipment, or where future work of a like character may be expected, the use of one of the other three methods may be advised. The objection to the use of traction engines and trains is that the speed of haul is slow and the trains are clumsy to handle and of little use for other purposes. The advantages are that the traction engine may be converted into a steam road roller and used in the construction of the road, which fact is offset by the necessity for a roller at the time the traction engine is working unless the material is spread out a long time before the road construction work is started. A large amount of material, however, may be hauled for moderate distances at a low cost. It seems evident that the use of motor trucks, either with or without trailers or an industrial railway will be more advantageous than the use of a traction engine with trailers. The traction engine, however, may properly be employed when the road approaching the job is soft and a large tractive surface is required to support the tractor.

Motor Trucks. The present development of motor trucks has proceeded far enough to determine that for long hauls, where the service can be made practically continuous, the use of self-propelled vehicles running

at a moderately high speed is advantageous for hauling purposes. Consequently, for work where the hauls vary in length and the material may be handled quickly at the pit and on the road, the use of motor trucks properly organized is advised. The size and weight of these trucks is determined by the character of the road surface and bridges leading from the pit to the job. Consequently care should be made in the selection of standard equipment, recalling that in many instances the highway bridges are not designed for exceedingly heavy loads. Taking all things into consideration, the motor truck units should not be too heavy, since the heavier trucks are clumsy and expensive of operation and available only for certain specific jobs. Experience teaches that from 3 to 4-ton trucks give the best results under ordinary conditions. The trucks and trailers, if any, should have proper dumping bodies easily operated; those on the truck by power, and those on the trailers by gravity. These devices should be so arranged that the entire load can be deposited at once or spread evenly over the surface. The proper devices for regulating the amount of material to be deposited are easily devised; in fact, are part of the standard equipment of motor truck bodies. Motor truck haul may be used for distances from 1 mile up, but great care should be taken to see that the trucks are constantly in operation and kept in good condition mechanically so that the loss of time and consequent expense due to the failure of transportation machinery may not occur.

The Use of Industrial or Narrow Gage Railroads is also of extreme value in certain cases. Briefly, the equipment consists of, first, narrow gage railroad tracks built in sections easily handled with portable switches, turnouts, and simple turntables; second, trains of small cars hauled by steam or gasoline engines or by a continuous cable. Such devices are common and easily secured. The value of this method lies mainly in the fact that for long road jobs, the railroad may be laid alongside the road or even on the subgrade without causing the damage to the subgrade which results from the continuous use of wagons or motor trucks. Large quantities of material are easily and quickly handled at a low cost provided the size of the job is large enough to warrant the initial financial outlay or that there is reasonable future opportunity for the employment of the plant. The objection to this method is that it affords no mechanical means for spreading the road material and there is usually an added expense for handling the material on this account. For this reason the use of trucks and spreading wagons is favored.

Special Methods for Excavation and Hauling. Interesting instances and devices for handling gravel which have been used are here inserted for suggestive information.

Wheel scrapers for excavating the gravel from a shallow pit combined with a double incline leading over a hopper so that the wheel scrapers might be continuously in service, and wagons loaded by gravity beneath the hopper.

Steam shovel loading from the bank directly into a portable crusher where the material was very stony and the face of the bank high. From the bins, which were extra large, a stream of teams and motor trucks carried the material on a short or long haul as the needs might arise.

Single carts assisted by a snatch block and hoisting line hauled up an incline from the pit to an elevated platform above screens and bins. Thence the material passed by gravity thru screens and bins into an industrial railway train beneath.

Dumping wagons of the ordinary wing bottom with dumping chains so set that the material could be spread over a long distance in windrows and spread into place with a light road machine.

With the local problem in view, the engineer may devise different combinations of the above methods or additional devices that may best fit his immediate needs.

Cost Data. The cost of excavating, screening and hauling gravel varies so widely in different localities on account of the character of labor, length of working day, prices paid per day for labor and the character of the equipment used, that it is hardly possible to give any definite rule for estimating the cost of these different items. Nevertheless, for a considerable length of road with easily available gravel banks and an average haul not exceeding one mile, the cost of gravel delivered on the road may be considered as $1 per cu yd. Variations in local conditions make it evident that no standard, which can be relied on and used for all work, can be stated as to the cost of the above items. Certain figures, however, compiled by different authorities will be of interest: Rogers (20) gives the cost of excavating gravel as from 10 to 15 cents. Elbe (14) gives the cost of crushing, hauling and spreading gravel using crusher, traction engine and trailers as 42½ cents per ton. The length of average haul is not given. Different authorities state that the cost of spreading gravel varies from 2 to 5 cents a ton. General experience teaches that for ordinary pits, where the material is easily available, 15 cents per cu yd can be charged for excavation and 6 cents per cu yd for screening; for team haul, over ordinary earth roads, about 30 cents per ton a mile or approximately 40 cents per cu yd mile. For traction engine or truck, for distances varying from 1 to 5 miles, the cost varies from 12 to 20 cents per cu yd mile.

Hauling and Spreading Gravel with Motor Trucks (15b). In the following table are given detailed costs, during the period from July 1, 1915, to May 1, 1916, of hauling and spreading gravel with one White Motor truck and two 3-yd trailers in MONTGOMERY COUNTY, ALA.

	Cu Yd Hauled	Total Cost	Average Haul In Miles	Class of Road Hauled Over	Cost per Cu Yd	Cost per Cu Yd Mile
July.....	1711.5	$319.58	1.26	Soft gravel	$0.1867	$0.1481
Aug.....	1029.0	283.85	2.10	Loose gravel	0.2753	0.1310
Sept.....	1121.5	461.22	3.43	Loose gravel	0.4112	0.1198
Oct.....	607.0	346.22	4.00	Loose gravel	0.5703	0.1425
Nov.....	667.0	336.57	5.00	Loose gravel	0.5046	0.1009
Dec.....	471.0	329.54	5.60	Loose gravel	0.6996	0.1249
Jan.....	385.5	280.97	6.00	Loose gravel	0.7288	0.1214
Feb.....	459.0	310.98	3.60	Loose gravel	0.6770	0.1880
March...	1456.0	452.49	2.30	Gravel	0.3107	0.1350
April....	1470.0	381.40	2.95	Gravel	0.2600	0.0880
	9377.5	$3502.32				

Average costs, using four White trucks, each hauling two 3-yd trailers, for the period July 1, 1915, to May 1, 1916, were as follows:

Total number of yards hauled	28 923
Total yd-miles	95 775
Total cost	$12 401.62
Average cost per truck per month	364.75
Average cost per yd	$0.4218
Average cost per yd-mile	0.1290
Maximum cost per yd-mile	0.2800
Minimum cost per yd-mile	0.0416
Maximum haul	11.4 miles
Minimum haul	1.1 miles
Average haul	3.2 miles
Maximum material hauled per truck per month	1778 cu yd
Minimum material hauled per truck per month	233 cu yd
Average material hauled per truck per month	850 cu yd

Hauling with Wagons. An analysis of cost data covering hauling of gravel in Steel County, Minn., is given in the following table, the figures being based on current rates in 1915, namely, 25 cents per hr for a laborer and 40 cents per hr for team and driver.

Length of Haul	0–½ Mile			½–1 Mile		
Job No.	1	2	5	1	2	5
Total number of loads hauled	407	475	482	327	1571	364
Average number of teams hauling	7.2	5.2	4.5	9.6	7.0	9.0
Average number of loads per team day	12.1	14.0	9.45	9.75	11.67	7.85
Load miles per team day	4.24	4.62	2.83	7.31	8.75	5.51
Percentage of time dumping, 5 min per load	10.0	10.9	7.8	8.1	9.7	6.1
Average actual time in pit per load	30.6	25.0	46.0	26.6	16.5	46.7
Percentage of actual time in pit per load	61.7	58.3	73.3	48.2	32.0	57.2
Percentage of time required for loading at 12 min per load	24.2	28.0	18.9	19.5	23.3	14.7
Percentage of time actually lost in pit	37.5	30.3	54.4	23.7	8.7	42.5
Average number of teams at pit	4.5	3.0	3.3	4.1	2.2	5.1
Hauling cost per cu yd in cents	21.9	19.0	28.3	27.3	22.9	36.3
Total cost per cu yd in cents, loading and hauling	29.9	28.0	38.3	34.3	30.9	46.3
Contract price per cu yd in cents	45.0	39.0	35.0	60.0	50.0	45.0
Spreading cost per cu yd in cents	2.0	2.25	3.75	1.75	2.0	2.5
Hauling cost per cu yd mile in cents, actual	73.0	57.6	94.3	36.4	30.5	48.4
Hauling cost per cu yd mile in cents with 12 min for loading	43.0	43.0	43.0	27.8	27.8	27.8

Length of Haul	1–1½ Mile			1½–2 Mile		2–2½ Mile	2½–3 Mile
Job No.	1	2	3	1	3	3	3
Total number of loads hauled	606	525	898	312	873	337	267
Average number of teams hauling	6.5	7.6	7.0	6.4	7.5	8.0	7.2
Average number of loads per team day	7.0	9.1	7.55	5.4	6.9	4.6	4.0
Load miles per team day	8.75	11.38	9.44	9.4	12.1	10.3	11.0
Percentage of time dumping, 5 min per load	5.8	7.6	6.3	4.5	5.8	3.8	3.3
Average actual time in pit per load	30.7	11.0	24.4	36.0	11.5	36.0	35.1
Percentage of actual time in pit per load	35.9	16.7	30.7	32.5	13.3	27.2	23.4
Percentage of time required for loading at 12 min per load	14.0	18.2	15.1	10.8	13.9	9.2	8.0
Percentage of time actually lost in pit	21.9	.....	15.6	21.7	....	18.0	15.4
Average number of teams at pit	2.3	1.8	2.2	2.0	1.0	2.2	1.7
Hauling cost per cu yd in cents	38.1	29.4	35.3	49.4	38.4	58.0	66.7
Total cost per cu yd in cents, loading and hauling	49.1	39.4	47.3	66.4	51.4	76.0	89.7
Contract price per cu yd in cents	70.0	65.0	65.0	85.0	80.0	107.5	122.5
Spreading cost per cu yd in cents	3.75	2.5	3.0	5.0	3.2	4.5	5.7
Hauling cost per cu yd mile in cents, actual	30.5	23.5	28.2	28.2	22.0	25.8	24.3
Hauling cost per cu yd mile in cents with 12 min for loading	23.8	23.5	23.8	22.0	22.0	21.2	20.6

CONSTRUCTION

10. Types of Gravel Roads

Three Types. Gravel roads may be divided into three general types as follows: Natural gravel roads; roads built by the surface method of construction and roads built by the trench method of construction. There are two different standards of constructing the several types based on

the method of maintenance treatment to be followed after the road is constructed.

Gravel Roads with Bituminous Surfaces. For gravel roads which are to be maintained with a bituminous carpet, either of asphalt or tar, care should be taken to eliminate all clay or loam from the gravel so that it will not interfere with the proper adhesion of the bituminous material to the road surface or tend to cause muddy conditions in rainy weather. With properly screened gravel, this result may be easily obtained, but there are few natural gravel roads which do not contain a sufficient amount of loam to seriously interfere with the use of a bituminous carpet. The surface of gravel roads to be covered with a carpet should be more or less porous so that the material may penetrate slightly into the surface but should not be so porous as to allow the material to disappear within the road surface, and cause the road to roll into bunches on account of an excess of bituminous material contained therein.

Gravel Roads without Bituminous Surfaces. For roads which are to be left without a bituminous treatment or which are to be treated with some road preservative or dust palliative other than bituminous material, the addition of a certain amount of binding material is imperative.

11. Natural Gravel Roads

The most common type of gravel road is the one built from natural gravel banks; that is, roads built with unscreened bank material with the possible removal of the larger particles of stone. These roads are ordinarily constructed by dumping the material shovelled from the gravel bank onto the surface of old roads in such a manner as to widen them out and to adjust the cross grades so as to properly drain the surface of the road. A typical cross-section of a natural gravel road is shown in Fig. 1. After the gravel is deposited upon the surface of the road, it should be well handled

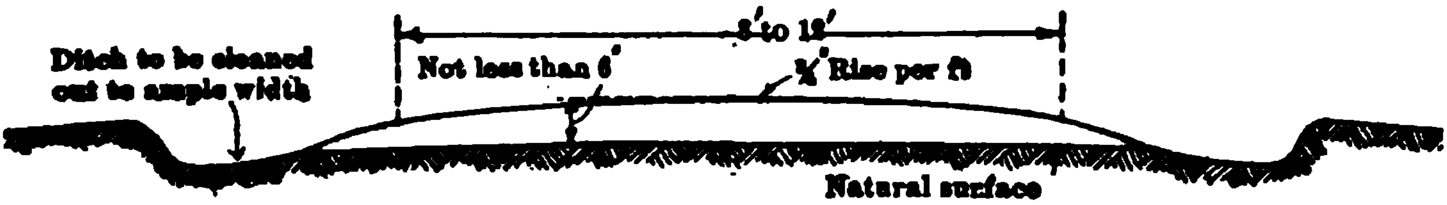

Fig. 1. Natural Gravel Road

over, leaving no piles undisturbed. Otherwise, since a portion of the road is compacted harder when the material is dumped and left in place, there will be a decided bump in the travelled portion of the road which can only be removed by harrowing or continued dragging. For roads under light country travel, this is a satisfactory method of procedure, but the following rules should be followed: If the road to be improved is exceedingly narrow, the grass on the sides should be removed and carted away from the road; the ditches should be deepened and proper drainage outlets provided.

Natural gravel roads are advisable in many instances where the material is easily available and where the road is not liable to be subjected to a large amount of motor travel, nor to a continuous travel thruout the year. Some of the easiest riding and most comfortable roads are those which are built by this method without the use of either roller or other device.

12. Surface Methods of Construction

The surface method of construction is known as the feather edge method; that is, where the gravel varies in thickness from nothing at the edge to

a considerable amount at the center, according to the foundation and the type of travel to which the road is to be subjected. A typical cross-section is shown in Fig. 2.

Width and Depth. Roads built by the feather edge method should be preferably not less than 18 ft in width so that a sufficient thickness of gravel will occur underneath that portion of the road which is subjected to travel. They should be 8 in in depth in the center and should be so constructed as to provide a cross-section as shown in Fig. 2. The subgrade should be prepared with a road machine so as to give the above desired result, and all vegetable and similar material should be well removed from the edges and subgrade of the road. The gravel should not

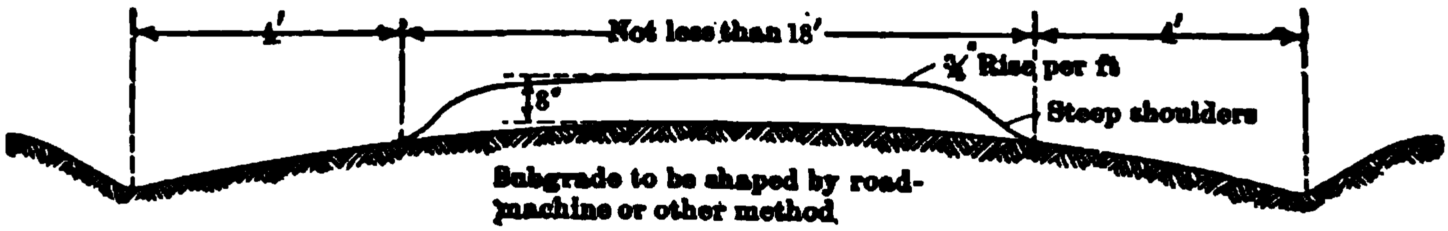

Fig. 2. Surface Method of Construction

exceed 1½ in in the largest size and should contain a proper amount of sand and clay. The larger sizes of stone should be laid in the lower course, and the material should be as evenly graded as possible, as the particles which go to make it up will gradually readjust themselves in position so that larger stones may come to the top. The courses laid in the road should not exceed 4 in in depth and should be harrowed before rolling so as to properly mix the material together. The harrowing, however, should not extend into or disturb the subgrade. Each course should be firmly rolled with the use of watering carts and steam roller if the road is to be used by motor vehicles immediately after construction or if it is to be later treated with bituminous material. The roller may be dispensed with, however, if the construction of a smooth surface can be deferred for sometime after the construction of the road since this surface can be secured by the use of some form of road drag continuously applied as mentioned in Art. 17.

Ill. State Highway Dept. Specifications for the feather edge method are as follows:

"Before any gravel is hauled onto the road, the cross-section of the road should be brought to the requirements of the plans, and the entire width of the graded roadway should be thoroly rolled until it is of practically a uniform density at all places. At least the portion of this roadway that is to form the subgrade for the gravel should be dry, compact, almost perfectly smooth and should have such cross-slope as may be necessary to shed readily any surface water that might fall thereon. The rolling should preferably be done with a three-wheel self-propelling roller weighing from about 300 to 400 lb per in of width of tread on each rear wheel. If such a roller is not readily available, a tractor of similar design and having approximately the same weight will usually answer the purpose very well. During the process of rolling, it will often appear to be entirely unnecessary and in fact it frequently is, but the purpose of the rolling is quite as much to detect the location of soft and yielding spots as it is to consolidate the roadbed generally. It is essential that these spots be detected before gravel is placed upon the road. When they are detected additional material should be added until the yielding ceases, and it may even be discovered that water pockets some distance beneath the ground surface will need to be released to an open channel. There should not be left on the graded roadway at any time berms of earth or other material that would interfere with the immediate drainage of its surface."

13. Trench Methods of Construction

The trench method of gravel road construction may be defined as that method which includes the construction of the shoulders for the support of the gravel roads before the road material is deposited on the roadway. This method of construction demands a greater attention to drainage, since the trench may become a receptacle for water if proper drainage is not provided. Most gravel roads which are designed for state road work or for moderately heavy travel are built by this method since the shoulders form a firm support to the edge of the road and the thickness is uniform, giving uniform support to the loads carried and allowing for greater care in the construction of the road and the compaction of the material which goes into it. A typical cross-section is shown in Fig. 3.

Shoulders. In constructing a gravel road by the trench method, the shoulders should be constructed in such a manner that they may be cut back to lines after they are placed and should be left sufficiently high so that they will compact flush with the surface of the gravel road when constructed. They should be constructed of good material, and no vegetable or other similar matter should be allowed to remain close to the gravel road.

Number of Courses. Practice varies as to the number of courses to be constructed. Ordinarily, however, there should be at least two and not more than three. With two-course roads, the coarser material should be placed in the first course, and thoroly rolled, partly bound with binding material and left porous on the surface to allow the top course to be added. The top course should consist of material graded so as to give a uniform size and with sufficient binder to keep the surface firm either until it can be treated by the bituminous carpet method or by the use of dust palliatives. If the road is to have no treatment, an excessive amount of binder should be added. A three-course road should be treated in the same manner

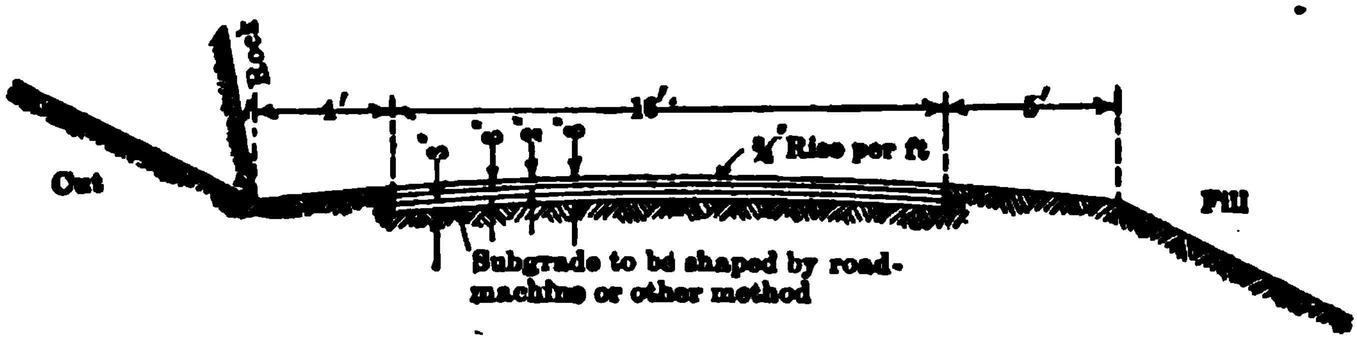

Fig. 3. Trench Method of Construction

with the exception that the lowest course may contain larger material than the bottom of a two-course road. This course may make use of some large material which cannot be used in the upper courses.

Thicknesses of Courses. The thickness of a course should not be more than 4 in in the case of two-course roads and 3 in in the case of three. The top course in both types of road should not exceed 2 in in thickness.

Sizes of Gravel for Different Courses. For a two-course road, the bottom course should consist of gravel varying in size from ½ to 1½ in, the material to be evenly graded so as to give a fairly close mixture. The top course should consist of material from ⅛ to ½ in with the proper amount of binder added. For a three-course road, the bottom course of road may consist of particles as large as 3 in, but the material should be so graded as to prevent the larger particles from forcing their way up thru

the upper courses. The second course should consist of material from ½ to 1½ in in size evenly proportioned so as to give a fairly close appearance, and the top course should be as specified for a two-course road.

Spreading. The ordinary specifications for spreading the gravel should provide rigidly for the entire rehandling of the material in order to prevent hard spots which will result from dumping on the subgrade. The same result, however, may be secured in different ways: First, by dumping the material on the side of the road and rehandling into place; second, by dumping the material on boards placed beneath the wagon and rehandling the material from these boards; third, by dumping in piles a sufficient distance enough ahead of the work so that the material must be entirely rehandled; fourth, by the use of proper dumping wagons in order that the material may be spread evenly either in windrows, or layers on the surface of the road. In this case the material may be handled into place by the use of forks, rakes or a road machine. The material for the upper courses of the road should never be dumped directly upon the finished courses beneath, since this will result in the irregular compaction of the surface which can only be removed by harrowing or by continuous dragging during wet weather.

Compaction. If a smooth surface is desired immediately upon the opening of the road to travel, the use of a steam road roller is imperative. If, however, the road can be allowed to self harden, a gravel road may be built without the use of a steam road roller, and by continuous harrowing and dragging and the occasional addition of binding material, the road may eventually be brought to a hard and smooth surface. No matter how much rolling is employed, soft places may eventually occur in the surface of the road, and it will be necessary, therefore, to provide for additional material and for future dragging as the road matures. In no case should a bituminous carpet be added to the road until it has had sufficient time to thoroly compact and develop soft or weak spots.

14. Specifications for Trench Methods

The following specifications were adopted in 1916 by the Am. Soc. Mun. Imp.

"**General Description.** The gravel road shall consist of three courses of mixtures of gravel, sand and clay, separately constructed, laid to conform to the required grades and cross-sections and constructed as hereinafter specified. The transverse slope of the finished surface of the gravel roadway shall be 1 in per ft.

"**Subgrade.** The subgrade for the gravel roadway shall consist of the natural earth roadbed prepared and rolled until firm, hard and even, and shall conform to the specified cross-section. If sandy or other soil be encountered which will not compact readily under the roller, a small amount of clay, or other means satisfactory to the Engineer, shall be used until a firm, even surface is obtained after rolling. Where the proposed grade allows the use of an old roadway for the subgrade, the roadway shall be shaped and rolled to the specified cross-section and elevations and depressions removed so as to form an even surface before the construction of the first course. The roller used shall be a 10 to 15 ton road roller.

"**Shoulders.** After the roadbed has been graded, shoulders of firm earth or other suitable material, 8 in in depth after compaction, shall be constructed on each side of the roadbed at such distances apart as may be required to retain the width of gravel specified. No material which contains weeds, sod, roots, or other perishable matter and which will not compact under the roller shall be placed in the shoulders. The shoulders shall extend to the side ditches or gutters with the same transverse slope as required for the finished roadway surface and shall be thoroly rolled at the same time as the third or wearing course.

"**Quality of Gravel.** All gravel shall be hard and tough. Gravel which contains over 10% of disintegrated stone shall not be used.

"**Sizes of Gravel Mixtures.** Two mixtures of gravel, sand and clay shall be used hereinafter designated in these specifications as No. 1 product and No. 2 product.

No. 1 product shall consist of a mixture of gravel, sand and clay, with the proportions of the various sizes as follows: All to pass a 1½-in screen and to have at least 60 and not more than 75% retained on a ¼-in screen; at least 25 and not more than 75% of the total coarse aggregate, material over ¼ in in size, to be retained on a ¾-in screen; at least 65 and not more than 85% of the total fine aggregate, material under ¼ in in size, to be retained on a 200-mesh sieve.

No. 2 product shall consist of a mixture of gravel, sand and clay, with the proportions of the various sizes as follows: All to pass a 2½-in screen and to have at least 60 and not more than 75% retained on a ¼-in screen; at least 25 and not more than 75% of the total coarse aggregate to be retained on a 1-in screen; at least 65 and not more than 85% of the total fine aggregate to be retained on a 200-mesh sieve.

"**Test of Gravel Mixture.** The mixture of gravel, sand and clay of the No. 1 product shall be subjected to a cementation test conducted by the Engineer in accordance with the method recommended by the Special Committee on 'Materials for Road Construction' of the Am. Soc. C. E. in Jan., 1916, and as described in the 1915 Proc., p. 2738, except that the test shall be made on material which will pass a ¼-in screen. Its coefficient of cementation shall not be less than 50.

"**Construction of First Course.** After the subgrade or subbase course shall have been prepared as specified, a course of No. 2 product shall be evenly spread so that it shall have, after rolling, the required thickness of 3 in. The depth of the No. 2 product loose shall be gaged by the use of strings between iron stakes, as directed. The spreading of the mixture of gravel, sand and clay must be from piles dumped on boards provided for the purpose or from piles dumped alongside the road. This course shall be thoroly rolled with a 10 to 15 ton road roller. The initial rolling shall begin at the sides of the road and continue towards the center and shall be kept up until there is no disturbance of the No. 2 product ahead of the roller. After the first course has been compacted, water shall be sprinkled on the roadway surface just ahead of the roller in such quantity as shall prevent the sticking to the wheels of the roller of the fine material on the surface, and the combined watering and rolling shall be continued until the voids of the gravel become filled with fine particles and until the roadway surface conforms to the specified cross-section. After the completion of the rolling no teaming other than that necessary for bringing on the No. 2 product for the next course shall be allowed over the rolled surface. The surface of the first course shall be maintained in its finished condition until the second course shall have been spread. Should it be apparent after the rolling of the first course that the subgrade or shoulder material shall have become churned up into or mixed with the material of this course, whether by reason of the rolling or by hauling over the surface, or otherwise, the Contractor shall at his own expense remove and replace such mixture of No. 2 product and subgrade or shoulder material with No. 2 product and shall roll the material to produce a uniform, firm and even first course as required.

"**Construction of Second Course.** On the completed first course shall be spread, in the manner specified in the preceding paragraph, No. 2 product to form the second course. This mixture of gravel, sand and clay shall be evenly spread to such depth that it shall have, after rolling, the required thickness of 3 in. The second course shall be compacted, puddled with water and finished under the same provisions as prescribed for the first course. When the rolling shall have been completed, the surface of the second course shall be firm, even and true to the lines, grades and cross-sections.

"**Construction of Third Course.** On the completed second course shall be spread in the manner above specified for the first course No. 1 product to form the third course. This mixture of gravel, sand and clay shall be evenly spread to such a depth that it will have, after rolling, the required thickness of 2 in. The third course shall be compacted and puddled with water under the same provisions as prescribed for the first course. When the rolling shall have been completed, the surface of the third course shall be firm, even and true to the lines, grades and cross-sections. If necessary to satisfactorily bond the roadway surface, the third course shall then be evenly covered with a thin layer of sand or sand and clay and rolled.

"**Measurement and Payment.** The quantity of gravel road to be paid for shall

be the number of square yards, measured horizontally, satisfactorily completed in accordance with the specifications. The price stipulated shall include shaping and rolling of the subgrade, the furnishing of the different products of gravel, sand and clay, the placing, rolling and watering of the several courses, and all work and expenses incidental to the completion of the gravel road. (The quantity of shoulders shall be paid for under a separate item.)"

As representing variations in practice throughout the United States to meet local conditions, the following excerpts from state specifications are quoted:

Alabama Specifications. "After the road has been graded and subgraded as specified, a coat of gravel, approved by the State Highway Engineer, or the Assistant Highway Engineer, shall be placed on the road to a depth of ...... in, and to a uniform width of ...... ft. This material must be dressed with a road machine or dragged until the surface is hard and firm and free from holes and bumps and until every particle of gravel is thoroly nested. No gravel must be placed on the road when the surface of the subgrade is wet or spongy. The road must present a smooth even surface, free from dips or high places, and must conform to the grade and cross-section shown on the profile and plans. The ditches must be parallel to the center of the road, except where it is possible to turn the ditch away from the road. The contractor must see that no strippings, earth or other inferior or non-road building material is placed on the road. Where such material shows on the road the contractor will be required to move same and place instead, material that has been approved by the Engineer or his Assistant.

"CLAY. When it is deemed necessary by the Engineer to place sand-gravel on the road, a good quality of mineral clay approved by the Engineer, will be required mixed with said sand-gravel to make a firm bond of the mass. The mixing of the clay and gravel on the road must be done in strict accord with the following directions: Where possible, the wagons must be loaded ⅓ clay and ⅔ gravel and dumped on the road. Where such is not possible, 4 in of clay must be hauled and placed on the road, after which 5 in of gravel must be placed on said clay. In both cases after 400 or 500 lin ft of the mass has been placed, a thoro plowing must be given the road so that the clay is well broken; after such plowing the entire mass must be harrowed until the gravel and the clay are thoroly mixed. After the thoro mixing and the road has sufficiently dried out, it must be properly shaped so as to have a fall from center to ditches of 1 in to the ft and then thoroly rolled. In the event a lack of mixing is apparent, the contractor will be required to repeat the process until the mass is well mixed."

Kentucky Specifications. "SHOULDERS. During the preparation of the subgrade and before any stone is placed thereon, shoulders shall be built along each side, as indicated on the cross-section drawings. They shall be built to a sufficient height to permit placing the lower course of gravel against them, shall be true to the alignment of the edge of the gravel and shall have the side next to the gravel as nearly vertical as the natural soil will permit. The shoulders may be built for both courses of gravel before any gravel is placed and the Contractor may use side boards having a height equal to the loose depth of the gravel. But, after the first course of gravel has been rolled, the shoulders must be made true and properly shaped before the second course of gravel is laid. Only selected material which readily compacts under the roller and contains no weeds, sod, roots or other perishable matter shall be used for shoulders.

"GRAVEL, FIRST COURSE. A layer of gravel shall be spread on the prepared bed to such thickness and width as shown on the plans. The gravel for this course shall be not less than 2 in nor more than 4 in, measured on the greatest diagonal. It shall contain not more than 25% of material less than 2 in in size, reasonably well distributed thruout the mass. It must be evenly spread; and after wetting, rolled to compactness and must present a true surface to the finished roadbed.

"GRAVEL, SECOND COURSE. The second course of gravel shall then be added of such thickness and width as shown on the plans. The gravel for this course shall be not less than ½ in nor more than 2 in, measured on the greatest diagonal, and shall contain not more than 25% of material of less dimensions, or of sand and clay, reasonably well distributed thruout the mass. Binding material, of such quality and sufficient to fill all voids as directed by the Engineer, shall be evenly spread over this course.

The whole shall be uniformly spread, well flushed and firmly compacted until the surface becomes smooth and rounded as shown on the plans."

Maine Specifications. "Gravel shall be furnished by the contractor from banks approved by the engineer and shall be of a quality satisfactory to the engineer. In general it shall consist of hard, sound durable stones of various sizes, ranging from pea stone to a maximum size of 3¼ in. The quality of the binding material shall be determined by the engineer. The amount of binder contained in the gravel shall be not less than 15% nor more than 25% and, in case the fine material which occurs in the bank is deficient or is not suitable as a binder, the contractor will furnish suitable material and spread a layer of such material on each course, mixing and rolling the same, as directed by the engineer until it is thoroly bonded. Gravel shall be spread in either two or three courses. The roller shall weigh at least 10 tons. Any depressions shall be filled and compacted, at the time they appear, with the same material which is being used.

"TWO-COURSE ROAD. Whenever the smaller sizes of stone predominate, the bottom course shall have a thickness of 4 in after rolling. This course shall be bonded with a fine material before the second course is applied. The second, or top course, shall be similar to the bottom course and shall have the same thickness. It shall be bonded with fine material until a firm, hard, smooth surface is produced. The rolling of each course shall be done while the gravel is wet, using a sprinkler if so ordered by the engineer.

"THREE-COURSE ROAD. Whenever the larger sizes of stone predominate the bottom course shall have a thickness of 3 in after rolling. The second course shall be of the same kind of material and of the same thickness. The top course shall have a thickness of 2 in after rolling and contain stone not larger than 1½ in in size. Each course shall be thoroly bonded with fine material by mixing, rolling and sprinkling until a firm, hard, smooth surface is produced.

"SPREADING. Spreading wagons may be used when approved by the engineer. When dump carts are used the gravel shall be dumped upon a platform or upon the ground on the sides and then spread uniformly over the surface to be built. It may be also spread with shovels from the carts. The contractor shall deposit where directed by the engineer, along or near the edge of the road in piles neatly formed and approximately 500 ft apart, 5 cu yd of gravel for use in maintenance of the road. The gravel surface when finished shall conform to the lines and grades given by the engineer in accordance with plans and specifications. No allowance will be made for material which may be driven into the subgrade by rolling.

"Payment for gravel roads will be made per cubic yard compacted into place in accordance with the thickness specified on plans.

"Gravel for maintenance shall be paid for at the price bid per cubic yard, but measured in the wagon at point of delivery on the road."

Massachusetts Specifications. "Before the surfacing is spread the roadbed shall be shaped to a true surface conforming to the proposed cross-section of the highway and rolled by a steam roller, unless otherwise ordered by the Engineer. All depressions occurring must be filled with suitable material and again rolled, until the surface is smooth and hard. The cost of shaping and rolling the roadbed shall be included in the price paid for excavation and for furnishing the material used, and shall not be additional thereto.

"On the roadbed prepared as hereinbefore described, gravel of a quality satisfactory to the Engineer shall be spread for the width of 18 ft, and to a depth of 6 in at the center and 4 in at the sides of the roadway, after rolling. The gravel shall contain no stones measuring over 3 in in their longest dimensions. It shall be spread from a dumping board, and care shall be taken while spreading the gravel to rake forward and distribute the largest stones so that they will be at the bottom of the gravel course and be evenly distributed. The gravel so placed shall be thoroly watered and rolled with a steam roller to the satisfaction of the Engineer. Any depressions that appear during or after rolling shall be filled with gravel and re-rolled until the surface is true and even. The surface of the roadway when completed shall present such a crown as the Engineer may direct."

Minnesota Specifications. "The subgrade, before being gravelled, shall be dressed to cross-section shown on plan and must be thoroly compacted, free from ruts, waves and undulations. Gravelling upon a wet, muddy roadbed will not be permitted.

Lines and grades will be given by the engineer in charge and gravel will be deposited to rope lines laid true and parallel to the center line at the specified distances.

"The width and thickness of completed gravel roads to be built under these specifications will be as shown on typical cross-sections made a part hereof. The gravel shall be furnished by the county and of a quality approved by the engineer, and the location of the pit from which the same is to be taken, will be designated in the statement of quantities. When clay base is called for by specifications, such base shall be deposited in advance of the gravel and uniformly distributed to required width and thickness, and rolled with a 5-ton roller or dressed with a road machine and road drag as specified.

"No earth, sod nor any foreign or vegetable matter will be allowed in the gravel, and care must be taken that strippings be not mixed with the gravel. Any loads taken to the work containing such objectionable material will be rejected or used for filling if such is required and paid for at a price not exceeding that for which the nearest material can be loaded and hauled, or, if not used, will be taken away from the work and deposited as the engineer may direct, at the cost of the contractor. The gravel shall be brought to a firm, compact surface, free from ruts, waves and undulations. This shall be accomplished by means of a roller of not less than 5 tons weight, or by a system of maintenance by means of dragging and hand raking for a period of at least 30 days from completion of placing same.

"The contract price shall include, unless otherwise specified, the necessary stripping of pits, loading, transportation, dumping, spreading, maintaining or rolling as required and any necessary work to bring the gravel surfacing to cross-section hereinbefore specified, in a complete and workmanlike manner.

"The engineer will furnish the bidders information relative to pit locations, the results of test pits and borings, and determination of quality and quantity of gravel where such determinations have been made, but any information furnished to bidders in this respect by the engineer shall not be considered as binding upon the contracting county, nor as a basis for extra charge above contract price, as bidders must visit proposed pit locations and satisfy themselves as to the availability of gravel.

"Unless otherwise specified gravel will be measured in the wagon boxes as delivered on the work and checks showing the amount delivered in each load will be furnished the teamster by the inspector in the employ of the county. The gravel placed on the road will be in excess of measurements on the plan at time of placing, but the contractor will be required to deliver wagon measurement in amount specified for each 100 ft station.

"SUB-GRADE. The roadway shall be graded approximately to cross-section as shown on diagram, having a width of 17 ft at a depth of 7 in below grade at center and 12 in below grade at sides. All soft spots or vegetable matter shall be removed from roadway, and the center 17 ft thoroly rolled or compacted, as directed by the engineer. When fill is over 5 ft high, the roadway shall be 24 feet with crown of 12 in.

"GRAVEL SURFACING. The gravel used shall be an approved pit gravel, containing not more than 10% of sand nor more than 15% of clay. Same shall be free from stone of over 2 in in diameter. Sand and clay proportions may be altered at direction of engineer when surfacing is to be used on heavy clay or sandy roads. In placing gravel, same shall be shovelled into place, and not dumped on road in such a manner as will develop wavy surface after settlement. All stones of over 1 in in diameter must be kept at least 4 in below finished surface. The gravel shall be deposited on the center of the road 17 ft wide at base, and 16 ft wide at top, rolled to a thickness of 7 in at center and 5 in at 8 ft from center. If for any reason rolling is not done, work will not be accepted until 3 months after gravel is placed, or until same has permanently set, and contractor will be required to keep same raked smooth and in good condition until accepted by the engineer.

"SHOULDERS. After the gravel is thoroly compacted, the shoulders of earth shall be brought to cross-section shown, leaving the roadway with uniform crown as required on the diagram, the whole roadway to be rolled or dressed as directed by the engineer."

Maryland Specifications. "The portion of the roadbed prepared for the gravel shall be below the sides an amount equal to the thickness of the first course of gravel so as to prevent the gravel spreading at the sides. The shape for the roadbed shall be as shown on the accompanying plans and shall have a cross-slope of ...... in to 1 ft.

"FIRST COURSE. Material. The first course of the gravel surfacing shall consist of gravel of sizes varying from sand to 2½ in, no pieces to have a dimension greater than 2½ in. This is known as No. 1 size. If more than 25% of the gravel will pass ¼-in screen, all the gravel for this course must be screened if required by the Engineer. No material shall be used which, in the opinion of the Engineer, is unfit for the work. If any such material is put upon the road it shall be removed immediately upon notice from the Engineer and replaced by proper material at the Contractor's expense.

"Spreading. No gravel shall be spread before the roadbed has been made as specified. The gravel shall be spread upon the roadbed, prepared as herein described with shovels from piles alongside the road, or from a dumping board; or it may be spread directly from wagons, especially constructed for this purpose and approved by the Engineer, but in no case shall the gravel be dumped directly upon the roadbed.

"Rolling. After the gravel for the first course has been spread to the required thickness, and has a proper cross-section, it shall be rolled with a steam roller, weighing not less than 8 tons, until it is compacted to form a firm even surface. Should any difficulty be experienced while rolling in having the gravel readily compact, sprinkling with water or lightly spreading with sand or other material, as the Engineer may approve, shall be employed. The rolling must begin at the sides and work toward the center thoroly covering this space with the rear wheels of the roller.

"Unevenness and Depressions. Should any unevenness or depressions appear, during or after the rolling of the first course, they shall be remedied immediately with gravel and rerolled until a firm, even surface is obtained. After the first course has been thoroly rolled and compacted, should the subgrade material appear to have churned up into or mixed with No. 1 gravel, if so directed by the Engineer, the Contractor shall, at his own expense and without extra compensation, dig out and remove the mixture of subgrade material and No. 1 gravel, and replace the same with clean gravel and thoroly reroll the fresh gravel.

"The thickness of the first course of gravel, after thoro rolling, shall be that of the class of gravel surfacing provided for any particular place as described under Classes A and B. If, for any reason, a greater thickness than specified is made by the Contractor no extra allowance for such additional thickness will be made.

"Shoulders. After the first course has been made as herein described, earth shoulders shall be constructed along each side of the road for a width of at least ...... ft as shown on the accompanying plans. Against these shoulders shall be spread the gravel for the second course as herein described. The shoulders shall contain a sufficient quantity of earth so that a smooth and continuous slope will be obtained after the shoulders and second course are rolled. The shoulders with the .... ft of gravel will make a total width of .... ft to be shaped as shown on the plans. Material for the shoulders must be free from roots, stumps or other vegetable matter and thoroly compacted by the roller. Material with a proportion of sand, such as prevents it when dry from compacting readily under the roller shall not be used, except under written approval of the Engineer. No material which is considered unfit for the work by the Engineer shall be used, and where any such is put on the work it shall be immediately removed, upon notice by the Engineer at the Contractor's expense. No first course material shall be spread on the subgrade when the latter is muddy or soft or in any way, in the opinion of the Engineer, unfit for receiving the first course.

"SECOND COURSE. The second course of the gravel surfacing shall be the same width as the first course.

"Material. The second course shall consist of gravel of sizes varying from sand to 1½ in; no piece to have a greater dimension than 1½ in. This shall be known as No. 2 size. If more than 20% of the gravel will pass a ¼-in screen, all the gravel for this course must be screened if required by the Engineer.

"Spreading, Rolling, Unevenness or Depressions. (Similar to requirements for spreading, rolling, unevenness or depressions under first course.)

"Thickness. The thickness of the second course of gravel, after thoro rolling, shall be that of the class of gravel surfacing provided for any particular place, as described under Classes A and B. If, for any reason, a greater thickness than specified is made by the Contractor no extra allowance for such additional thickness will be allowed.

"THIRD COURSE. Material. The third course of the gravel surfacing shall consist of clean, sharp sand with no particles larger than ¼ in.

"Spreading. After the second course of No. 2 gravel has been rolled and completed as above described the sand shall be spread, but in no case shall sand be used until the second course has been thoroly rolled and compacted. The sand shall be spread dry with shovels from piles alongside the road, or from dumping boards, but in no case is the sand to be dumped directly on the second course.

"Watering and Rolling. After the sand is spread it shall be sprinkled with water from a properly constructed watering cart, and then rolled with a steam roller weighing not less than 8 tons. The amount of water necessary shall be determined by the Engineer. The rolling shall begin at the sides and continue until the surface is hard and smooth and shows no perceptible tracks from vehicles passing over it. If, after rolling the sand, the No. 2 gravel appears at the surface, additional sand shall be used in such places. The rolling and watering shall continue until the water flushes to the surface. The rolling is to extend over the whole width of the road including the shoulders.

"Unevenness or Depressions. (Similar to requirements for unevenness or depressions under first course.)"

Connecticut Specifications. "KIND OF GRAVEL. The gravel shall be composed of a hard durable stone and assorted sizes of finer materials, sufficient but not more than sufficient to fill all voids. All gravel used under this specification must be screened. Care must be taken to have the gravel as near uniform in quality as possible, avoiding all shale gravel.

"COURSES OF GRAVEL. There shall be three courses, consisting of two courses 3 in in depth after rolling, and one course 2 in in depth after rolling. No allowance will be made for the settling of the subbase or the stone.

"SIZE OF GRAVEL. All gravel must be screened. The gravel for the first course shall range in size from pea stone to 3 in in its longest diameter. The gravel for the second course shall range in size from pea stone to 2 in in its longest diameter. The gravel for the finishing course must be of a nature suitable and acceptable to the State Highway Commissioner or his authorized agent and no stone shall exceed 1 in in its longest diameter.

"FIRST AND SECOND COURSES. The gravel shall be dumped on the side of the road where it is possible. If not, it can be dumped on the side of the roadbed on a platform and scattered with shovels. No forks, hooks or scrapers will be allowed. The reason for this is so that the gravel will have uniform resistance and pressure in rolling. A patent spreading wagon will be allowed. The gravel shall be spread uniformly and rolled down after which a sprinkler shall be used and this course wet down and then rolled again and the wetting and rolling shall be continued until the course is firm and thoroly compacted. This course shall be 3 in in depth when complete after rolling. After the first course has been finished the second course shall be applied and the same method shall be pursued in its treatment in every particular as described for the first course, except that the size of the gravel shall not be larger than will go thru a 2-in screen. This course shall be 3 in in depth after rolling. If in putting on either course, any settling is found, all such places must be brought up to grade level before any other course is commenced. All wheel tracks and footmarks of horses shall be carefully filled and then rolled down firmly on each course before the next course is applied.

"FINISHING COURSE. The material for this course shall be carted onto the sides of the road proper and dumped at suitable intervals before the rolling has been fully completed on the second course, after which all wheel tracks and footmarks of horses shall be carefully filled and then rolled down firmly. This course, after being spread uniformly, shall be wet down and then rolled, and the wetting and rolling shall be continued until the road is solid and firm and will not show the mark of hoof or wheel while driving over it.

"SPRINKLING WAGONS AND ROLLER. The contractor shall provide and use continually during the construction of the road, and until its final acceptance by the State Highway Commissioner, one vertical spray sprinkling wagon for each 2600 lin ft, or fractional part thereof, of said road. A steam roller weighing not less than 10 tons must be used on all work."

15. Construction Cost Data

Preliminary Data. In order to properly determine the cost of a gravel road before construction, a careful pre-survey of the ground should be made. It is assumed that the party requiring the cost has already figured the other items which go to make up the road construction job, and this paragraph will concern itself only with the cost of surfacing the road itself. In the first place, the gravel bank should be located and the average haul determined. In other words, the number of cubic yards of gravel to be used on the road should be calculated, and the work divided up into zones, and the cost per cubic yard of excavating, screening and hauling the gravel for each zone computed. This entire cost should be averaged over the whole job and to it added the cost of manipulation of material after it has been placed on or adjacent to the subgrade. The cost of manipulation, placing and rolling of the material will be the same for the entire length of the work; the only variation in figures being the cost of hauling the material to the point where it is to be used. In figuring the different items which go to make up the cost of gravel surfacing, it is impossible to give any exact figures as to what each item will cost, but a fair indication can be secured from cost data given below. Care should be taken to make necessary allowances for the local conditions, namely cost of labor, length of day, cost of teams, size of wagons, condition of teams to be secured, if teams are used, and the character and capacity of the men who will do the actual work.

Basis of Cost Data. Following is a statement of cost of the construction of different gravel roads separated as follows: First, the cost of gravel roads in those states for which the specifications are quoted. These costs are secured from information furnished by the highway departments of the several states, and must be accepted only as an indication of the average cost of work for the locality mentioned. Wide variation in the cost will be noticed. This is due to many factors. Principally, however, these are variations in cost of manipulation of material due to different specifications, length of working day, class of labor employed, and length of haul of material.

Alabama. DALLAS COUNTY. Selma and Richmond Road built in 1914; width of roadbed, 20 ft; width of gravel, 12 ft. Road was built with county convicts; cost of convicts per man per day for guard hire, medical attention and feeding was $0.303; average number of convicts, 45.

Distribution of Cost

Previously reported	$5672.88
Earth excavation	2306.92
Clearing and grubbing	110.00
Gravel	1300.00
	$9389.80
Engineering	25.00
	$9414.80
Miles completed, 2.75. Cost per mile	$1420.50

FAYETTE COUNTY. Guin Road built in 1915; width of roadbed, 20 ft; width of gravel, 12 ft. Work consisted of surfacing, with clay gravel, 4.54 miles of road; 7958 cu yd gravel used; cost per mile, $1052.72.

HALE COUNTY. Greensboro and Uniontown Road built in 1915; width of roadbed, 20 ft; width of gravel, 14 ft.

Distribution of Cost

Earth excavation, 7404 cu yd	$1628.88
Clearing and grubbing, 7 acres	35.00
Double strength vitrified pipe, 24-in, 65 lin ft	146.25
Concrete abutments, 49.73 cu yd	497.30
Gravel, placed, 1458 cu yd	1166.40
Force account	101.60
	$3575.43
Gravel	583.20
Freight on gravel	442.50
Steel bridge	270.00
	$4871.13
Engineering	153.14
	$5024.27
Miles completed, 1.06. Cost per mile	$4739.87

NOTES. It is evident from the cost shown for Alabama that the cost per cubic yard of gravel is the unit determined upon for this state. For the Fayette County Road, the cost for placing gravel is $0.60, which is a remarkably low cost if there was any manipulation or grading material. The Hale County Road, on the other hand, shows that the cost of placing the gravel was $0.40, while the cost of the gravel was $0.40 and the freight on the gravel was 30 cents, making the total cost of gravel in place

Cost of Gravel Roads in Maine, 1914

Name	Miles	Cost	Total Cost per Mile
Kennebunkport-Biddeford	2.03	$11618.16	$5723.33
Fryeburg	7.41	40886.79	5517.78
Woolwich	5.65	42555.50	7531.94
Waldoboro	7.09	52144.91	7354.71
Greene	2.28	12816.36	5621.21
Leeds	1.45	9021.80	6221.93
Madison	1.08	5676.32	5255.85
Newport	1.59	14197.19	8929.05
Trenton	6.02	34343.83	5704.95
Whiting	9.23	53767.53	5825.30

Cost of Gravel Roads in Maine, 1915

Name	Miles	Gravel Surface per Cu Yd	Cost	Total Cost per Mile
Wiscasset	3.90	....	$29638.71	$7599.25
Warren	5.80	$1.45	37423.81	6452.38
Monmouth	4.88	1.50	34211.01	7010.45
Winthrop	1.85	....	14771.92	7984.72
Farmington	3.62	1.49	26223.75	7244.13
Strong	3.44	1.59	26404.91	7675.84
Fairfield	2.29	1.19	10262.85	4480.50
Norridgewock	5.61	1.55	33793.60	6023.81
Etna	3.08	1.55	22344.07	7254.56
Carmel	4.92	1.15	28987.12	5891.69
Herman	1.09	1.30	8559.01	7852.30
Dover	6.72	1.20	39990.47	5950.96
Edmunds	1.95	1.24	14287.27	7326.80

on the road, $1.50, which compares favorably with the average cost for the State of Maine quoted on page 210.

Maine. The figures for 1914 and 1915 show the total cost per mile of gravel roads, and for 1915, average costs per cubic yard where the gravel surfacings are indicated.

Massachusetts. Following are average costs for gravel roads 6 in in thickness, not including any grading or other work except the gravel in place:

1912	$0 16 per sq yd.
1913....................................	0.28 per sq yd.
1914....................................	0 26 per sq yd.
1915....................................	0.21 per sq yd.

It is needless to state that the variation in these costs is due to the length of haul of the material. The average costs for all gravel roads for 4 years are given as secured from official sources.

Maryland. The following table gives cost data for the different parts of the work on several sections of gravel roads, 14 ft in width, constructed during 1912 and 1913.

of Road	Surveys [redacted] Plans	Grading	[redacted]	and Under-drains	[redacted] Super-vision	Miscel-laneous	Total	per Mile
4.64....	$339 71	$5865 16	$17179.74	$6644 51	$641.88	$823.01	$30994	$5679
6.25..	457.68	11258 42	27213 08	6055.78	1621 91	497 68	47004	7520
3.01....	220.37	3931 92	10792 00	1527.87	716.93	272 09	17461	5801
3.87....	283.84	9186 68	13918 67	1408 29	1050 99	305 70	26148	6756
5 02...	367.68	17443 02	26241 73	8778 38	631 71	1004 28	54466	10849
2 00 ...	146.45	4824.86	3181 84	527.19	602 05	223.11	9505	4752
6 12....	476.26	15968.71	19684 24	9567 76	1268 28	473 81	47439	7751
5 98 ...	465 47	12930 77	22971 73	10330 44	1024 57	553.73	48276	8073
1 00 ...	16.11	1520.59	4656 46	713 81	298.76	106.77	7312	7312

Connecticut. The figures in the following table indicate that the cost per square yard for surface varies considerably, but generally it is higher for the shorter lengths of roads. The extremely low prices quoted in Canaan, Chaplin and Eastford arise from the fact that a gravel supply of good quality was immediately available.

Year Built	Town	Name of Road	Miles	Cost per Sq Yd Surface	Cost per Mile of [redacted]	[redacted] Cost per Mile
1912.	Canaan	Huntsville	0 89	$0.21	$1724 80	$6198.07
1914	Chaplin	Hartford-Providence	3.07	0.22	1806.93	6482 04
1914	Colebrook	Norfolk	0 84	0 40	3286 34	10050.86
1914	Eastford	Hartford-Providence	3 87	0.22	1806.95	7744 81
1914	Franklin	Lebanon	1 60	0 37	3038.93	7491 66
1914.	Franklin	Lebanon	0 69	0.45	3696.80	7850.62
1914	Columbia	Hartford-Willimantic	3 13	0 30	2816 10	5951 56
1915	Windham	[redacted]	1.98	0 33	2710 40	6841 23

Michigan. Rogers (26c) states, in discussing the cost of gravel roads in Michigan, that there is "a great diversity of plant used and a wide range of conditions from suburban streets to roads thru uncut forests. An average cost based on 59 jobs, aggregating 68.42 miles of 9-ft gravel roads, is about $2500 per mile. With a ¼-mile haul, the cost was $2340, and with a 5-mile haul, $2850."

United States. In the following table are given, for several states, typical prices of gravel roads.

From *Municipal Journal*, Feb. 3, 1916

State	City	Cost per Sq Yd
Colorado	Denver	$0.20
Connecticut	Norwalk	0.25
Idaho	Pocatello	0.18
Indiana	Crawfordsville	0.44
Massachusetts	Framingham	0.30
Minnesota	Duluth	0.28
Pennsylvania	Freeland	0.29
Tennessee	Memphis	0.45
Tennessee	Paris	0.22
Vermont	Montpelier	0.22
Washington	Puyallup	0.18
Wisconsin	Waupaca	0.20

MAINTENANCE

16. Causes of Failure

A gravel road is easily destroyed, generally because of its lack of mechanical bond. With roads which are not superficially treated, the deterioration is rapid and increases far out of proportion to the weight of travel and the speed thereof. In other words, a gravel road subjected to slow moving travel of a light character will last for an indefinite period, but as the traffic increases in weight or speed, the wear on the road increases so rapidly that when the amount of travel reaches a certain number of vehicles or the units are heavy, the use of the gravel road is unwise. By far the most destructive agency tending to break up the gravel road is rapid motor travel. Consequently, a gravel road is limited in its use to those roads which are subjected to light and slow moving travel chiefly of a horse-drawn character. Nevertheless, this type of road may be superficially treated during maintenance in such a manner as to increase its use for travel and extend its scope beyond the number of units stated above as 100 motor vehicles per day.

17. Methods of Maintenance

As outlined in Art. 10, many gravel roads of necessity must be maintained under light travel without the use of bituminous or superficial treatment other than the natural material itself.

Ordinary Maintenance. Gravel roads built without any superficial treatment, that is, with gravel alone, can best be maintained in good condition by the proper use of a drag, either of the split log type or some variation thereof. There is no device in the whole list of road machinery which is of so much value in the proper maintenance of gravel road surfaces as the drag. In general, the drag should be used after rain storms or when the road is rutted in the fall or winter season just before freezing, and local arrangements should be made for the application of the drag when the road needs it. An instructive discussion of this device is issued by the U. S. O. P. R. (31).

Repairs. Repairs to untreated gravel roads may be made by placing a small amount of gravel in the depressions or ruts with a sufficient amount

of sand and finer binding material to keep the patches in place. These patches may be wet, but should be preferably placed in the road after a rain storm when the depressions are filled with water and easily located and filled to a proper surface. Repairs should be made carefully and periodically so that the defects of the road surface do not last long enough to cause a serious breaking up of the entire construction.

Reconstruction. Reconstruction of untreated gravel roads can best be carried on in the spring or in the fall when the road is soft and a coating of gravel may be given to the entire surface in such a manner as to replace the surface by new material fresh from the pit. Gravel which has been thrown out by travel on the sides of the road or washed out by rains is not fit for use. In no case should repairs or reconstruction be attempted by using any portion of the material from the sides of the road whether it be gutter-wash or turf.

Roads with Superficial Treatment. The maintenance of gravel roads which may be treated superficially will be considered as divided into two classes; as roads upon which a dust palliative, either of oil or some other material, is used, and second as roads treated with a bituminous carpet. Both types of treatment are designed with the idea either of laying the dust which in itself is a road protection or of applying some surface to the gravel road which will enhance its usefulness and allow it to be travelled more frequently and with heavier and faster vehicles. In either event, it must be borne in mind that the gravel road, however treated, is not suitable for heavy winter travel in locations of extreme temperature changes or for localities where continued rains are liable to occur, thus softening up the road itself.

Roads Treated with Dust Palliatives. The treatments of roads for the laying of dust and the incidental preservation of the surface may be divided into two classes: First, by the use of dust layers consisting of material of an oily character; and second, by the use of dust layers of hygroscopic nature. In each case, an attempt is made to keep the dust carpet from being blown away by the wind or being torn up by passing travel. In addition, the idea is to form a mat with this oily or moist dust upon the surface of the road which affords protection to the larger particles of road metal and prevents them from separating or ravelling, thereby disintegrating the road itself. The oily materials may be either asphaltic or non-asphaltic oils. In case of the asphaltic oil for dust laying, the oil should be applied to the road without cover. With the non-asphaltic oil, there should be a slight layer of clean dust upon the surface of the road which will form a mat with the oil and protect the road while keeping the dust in place. Material of this character, however, tends to form mud in wet weather.

With dust layers of hygroscopic nature, the idea is to collect moisture on the surface of the road by the use of this material and thereby make a moist mat or carpet on the surface of the gravel road protecting the larger particles, and also preventing dust from flying. When such materials are used, the road should contain a certain amount of clay or other binding material in order that the moisture and dust-laying material may be retained near the surface of the road and not pass down thru the voids into the bottom of the road where it will be of little or no value. These materials are generally made up of some alkaline substance, the most successful of which is calcium chloride or deodorized chloride of lime which has the property of attracting to itself water from the atmosphere or surrounding

sources of supply, thereby moistening the road surface and keeping it in a smooth and dustless condition under light traffic. The calcium chloride can be placed on the road from sprinkling carts in a saturated solution, or it can be spread dry shortly after a rain storm in such a manner as to form a moist mat as suggested above. Repairs to roads treated in this manner can be made by adding a small amount of the dust-laying material to the gravel patches in such a way as to make the patch of the same character as the remaining road surface. Ordinary rock salt in saturated solution sprinkled on the road has the same effect, but to a lesser degree. The sprinkling of gravel roads with sea water in the vicinity of the ocean or branches thereof will give the same results, but the sprinkling will have to be done frequently.

Gravel roads treated by either of the above methods can be resurfaced or reconstructed in the same manner as outlined for roads without treatment, namely by placing a light coating of fresh new gravel upon the surface of the road at the season of the year when the material will best incorporate itself with the old surface. For a detailed treatment of the subject of dust prevention by palliatives, see Sect. 13.

Superficial Bituminous Treatment. Gravel roads to be maintained by a superficial bituminous treatment should be constructed as outlined in Art. 10, using clean gravel without the addition of clayey binding material. The surface of the road itself should be bound together and made of close texture by the addition of fine particles of clean sand gravel or screenings in such a manner that an excess amount of the bituminous material will not enter into the road, thereby causing the road to roll under travel. The purpose of the bituminous carpet is to provide a covering for the gravel road, taking the wear from travel on the carpet of stone and bituminous material itself, lay the dust and protect the surface of the gravel from disintegration. For details of construction and maintenance of bituminous surfaces on gravel roads, see Sect. 14.

18. Maintenance Cost Data

The cost of maintaining gravel roads varies, of course, with the method of treatment which, in its turn, is determined by the volume and rapidity of traffic using the road. In the case of roads which are not superficially treated, the cost of dragging varies from \$15 to \$50 per mile per year. The road may be repaired at a cost not to exceed \$50 per mile per year. The total cost of dragging and repairs should not exceed \$500 per mile. When this point is reached, the use of some superficial treatment should be undertaken as a matter of economy. Calcium chloride may be applied at a cost of \$90 per mile for the material and \$90 for the cost of application. The cost of sprinkling periodically will vary from \$200 to \$500 per mile per year, depending upon the number of applications and the character of the travel. Bituminous carpets may be constructed for \$600 per mile with material at \$0.06 per gal, labor \$2 per day, teams \$5.50 per day and sand at \$0.10 per cu yd in convenient gravel banks. Reconstruction of these roads will vary from \$500 to \$1500 per mile. It may be easily determined that when the total costs of repairs, oiling and general maintenance reaches the sum total of \$1000 per mile it is time to discontinue the attempt to utilize the gravel road and proceed to the selection of some more rigid and durable type of road or pavement.

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SECTION 11

BROKEN STONE ROADS

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GENERAL DATA

1. Historical Development

Tresaguet's Method. Broken stone roadways were first systematically constructed in 1764 by Tresaguet, at that time Chief Engineer of the District of Limoges, Department of Roads and Bridges of France. Under his direction roadways were built in three courses. His method, as described by himself, was as follows:

"The bottom of the foundation is to be made parallel to the surface of the road. The first bed of the foundation is to be placed on edge, and not on the flat, in the form of the rough pavement and consolidated by beating with a large hammer, but it is unnecessary that the stones should be even with one another. The second bed is to be likewise arranged by hand, layer by layer, and beaten and broken coarsely with a large hammer, so that the stones may wedge together and no empty space may remain. The last bed of 3 in in thickness to be broken about to the size of a small walnut with a hammer on one side of a sort of anvil, and thrown upon the road with a shovel to form a curved surface. Great care must be taken to choose the hardest stone for the last bed, even if one is obliged to go to more distant quarries than those which furnish the stone for the body of

the road. The solidity of the road depending on the latter bed, one cannot be too scrupulous as to the quality of the materials which are used for it."

Telford's and McAdam's Methods. The next engineer to systematically use broken stone for roadways was Telford, in England, about 1805. His method was substantially the same as Tresaguet's, except that he made the subgrade level. A decade later John Louden McAdam expressed and demonstrated his ideas of road building, and since about 1825 broken stone roadways have been quite generally spoken of as macadam roads. McAdam contended that the foundation course of large stone was unnecessary and injurious; that any dry native soil or earth would carry any weight passing over a broken stone crust 10 in in thickness, provided the crust be thoroly consolidated. Consolidation was secured by traffic and not by rolling.

Comparison of Early Methods. Tresaguet and Telford used stones 6 or 7 in in maximum dimensions in the lower courses. Tresaguet used stone "the size of a small walnut" for the top course, while Telford used stone that would pass a 2½-in ring, and covered the whole surface with 1½ in of "good gravel, free from clay or earth." McAdam's belief as to sizes was expressed by himself as follows: "The size of stone used on a road must be in due proportion to the space occupied by a wheel of ordinary dimensions on a smooth level surface; this point of contact will be found to be longitudinally about an inch, and every piece of stone put into a road, which exceeds an inch in any of its dimensions, is mischievous." He later, in directions for road making, specified that no stone should exceed 6 oz, which corresponds to cubes about 2 in on a side. The methods of Telford and McAdam have, with some variations, been considered as standard even to the present day. For a detailed history of the construction of broken stone roads see (37).

2. Foundations and Subgrades

A suitable foundation is absolutely necessary for a broken stone road. If the natural subsoil is of gravel or sand, no artificial foundation is necessary. It was the theory of McAdam that any base that would support a man was sufficient to support a road surface, but this theory has been often proven purely theory rather than fact. A clay or loamy subsoil may support a broken stone surface in a climate where there is little or no frost and no extremely wet seasons, but in all localities where such conditions do not exist, the crust should be supported by an artificial foundation consisting of stone, sandy gravel or coarse sand. If the subsoil is of extremely fine silicious material a foundation consisting solely of stone will after a time become ineffective, due to the gradual filling of the voids in the stone with the silicious material of the subsoil. In such cases it is desirable to place 4 to 6 in of sandy gravel or coarse sand on the subgrade before placing the stone base. With a water-bound road, moisture is necessary to preserve the road, hence a foundation of gravel or sand is preferable to one of stone in localities where there are prolonged dry seasons, the gravel having a tendency to assist in the retention of moisture in the crust, whereas a stone foundation has a tendency to assist in drying the crust.

3. Crowns

The crown or camber at which broken stone roads are constructed should be sufficient to prevent water from running longitudinally over the road and to prevent the water from standing on the surface of the road. Until about 1910 a crown of ¾ in to the ft was almost universally adopted, and

since then has been quite commonly used. A greater crown tends to a concentration of travel in the middle of the road and consequent formation of ruts. As smooth bituminous surfaces are often constructed on water-bound roads after they have become worn to such an extent that the upper surface requires renewal, a crown not exceeding ½ in to the foot is often desirable.

MATERIALS

4. Physical Properties of Rock for Road Metal

Essential Physical Properties. The nature and quality of rock used in the construction of water-bound broken stone roads is of prime importance. The rock used should excel in three properties: namely, hardness to resist the wear caused by the grinding action of vehicles, of steel shod animals and of the stones against one another; toughness, to withstand the shocks or blows from traffic; cementing value, to bind the parts and particles together and thus cause the crust to be as near monolithic as possible. Trap, granite and limestone are most commonly used.

Trap excels either of the other two in hardness and toughness, but often lacks cementing power. Comparatively speaking, it wears but little under traffic, but a surface constructed of trap, while durable under traffic, becomes more rough than surfaces made with softer stone.

Granite, to be of value, should have a close and uniform structure. Granite of coarse structure is unfit for use except in foundations. A granite surface is good under light traffic, wears more rapidly than a surface of trap, but is sometimes more desirable as it presents after wear a smooth easy surface for light vehicles.

Limestone possesses greater cementing value than either trap or granite, but is not hard or tough. It is, however, a good material for light traffic for the same reason given above for granite.

Field Stones, consisting of round or irregular shaped cobbles are often crushed and used. Stone from ledge is more desirable than field stone because of its uniform quality. Field stones usually have to be culled or selected in order to secure uniformity in the crushed material. Lack of uniformity in quality of stone tends towards an uneven surface after the road has been subjected to wear.

For a detailed discussion of rocks for road metal, see Sect. 3, Arts. 1 to 6, inc.

Mineral Compositions of Rocks Used for Road Metal (32) are shown in Table I.

5. Tests of Broken Stone

Sampling of Rock and Broken Stone. The following method was adopted at the first conference of State Highway Testing Engineers and Chemists called by the U. S. O. P. R. in Feb., 1917.

" By Whom Taken. Samples are to be taken by the engineer or his authorized representative.

" When Taken. Samples are to be taken from the proposed source of supply at least ...... days before the stone is to be accepted or rejected, also from every ...... cu yd quarried, or when the quality or appearance of the stone changes, and at such other times as may be directed by the engineer.

" Where and How Taken. (1) Sampling for quality. Samples shall be taken either from the quarry or from cars as directed by the engineer

Table I.—Average Mineral Composition of Rocks for Road Making

No.	Rock Varieties	Mineral Composition, Expressed in Percentages																		
		Quartz	Ortho-clase	Plagio-clase	Augite	Horn-blende	Calcite	Dolo-mite	Chlo-rite	Biotite	Musco-vite	Kaoline	Epidote	Magne-tite	Micro-cline	Rock Glass	Garnet	Olivine	Serpen-tine	Hyper-sthene
1	Granite	31.0	45.8	7.3						3.8	3.4				3.7					
2	Biotite-granite	28.0	36.1	12.2						10.5					4.4					
3	Hornblende-granite	24.9	40.8	9.7		14.7				4.7										
4	Augite-syenite	4.3	60.1	4.7	7.8										9.9					
5	Diorite	6.2	5.6	33.0		34.0						7.2								
6	Augite-diorite		22.0	29.6	14.8	13.3				4.5				5.2						
7	Gabbro			42.7	26.3	11.0						7.2								
8	Peridotite				16.0									30.6				5.0	27.5	20.0
9	Rhyolite	38.0	42.1																	
10	Andesite	9.7		45.7	8.6		7.3		6.8				8.5							
11	Fresh basalt			36.1	45.0											8.2		4.5		
12	Altered basalt			28.6	24.9				10.2			10.3	5.1			10.3				
13	Fresh diabase			48.8	44.4															
14	Altered diabase			37.4	20.2	7.5			13.0					6.1						
15	Limestone	6.4					82.3	6.0												
16	Dolomite	8.6					7.5	78.6												
17	Sandstone	71.2																		
18	Feldspathic sandstone	42.1	24.3									20.6								
19	Calcareous sandstone	39.6	17.3				35.3													
20	Chert	94.2																		
21	Granite-gneiss	37.2	41.1							4.7	4.9									
22	Hornblende-gneiss	11.1	18.4			53.4														
23	Biotite-gneiss	40.9	33.2							12.9										
24	Mica-schist	39.3	14.8							14.6	19.2									
25	Biotite-schist	27.3	13.7			10.3				38.7										
26	Chlorite-schist	19.9	10.1						36.3				20.4							
27	Hornblende-schist	11.3		6.9		62.5														
28	Amphibolite			6.5		71.0							10.7							
29	Slate	25.9									63.8									
30	Quartzite	86.2																		
31	Feldspathic quartzite	46.8	33.7						5.7											
32	Pyroxene quartzite	36.0		25.1	22.2															6.7
33	Eclogite	5.0		28.8	14.5												38.4			
34	Epidosite	16.8				13.6							64.9							

and shall be sound interior rock, representative of that which it is proposed to use. Mixed samples may be taken if deemed necessary by the engineer. (2) Sampling for size. Samples of the crusher product shall be taken either at the crusher or from cars as directed by the engineer. The sample shall be mixed from runs of the crusher, on different days, or, if taken from cars, shall be taken from both ends and top and bottom of the car.

"AMOUNT AND SIZE OF SAMPLE: (1) Sampling for quality. A sample shall weigh between 25 and 40 lb, and shall consist of pieces of rock at least 1½ in in size, and one piece at least 3 by 4 by 6 in, free from seams and cracks, and with bedding plane marked. (2) Sampling for size. A sample for size shall weigh not less than 10 lb for materials of ¾ in maximum diameter or less. Samples of materials of other sizes shall increase in weight to a maximum of approximately 60 lb, varying with the size and weight of the largest pieces represented by the sample. The sample shall be representative of the product as delivered for use.

"MARKING and SHIPPING. Samples shall be shipped in tight boxes or bags and shall be accompanied by a card in the container or securely attached thereto, stating date, by whom taken, proposed purpose to which the material is to be put, space for remarks, and in case of quarry investigations, owner, quantity available, amount and character of stripping, whether material from same source has been previously used, where and for what purpose, and with what results, haul to nearest point on road, average haul to job, character of haul, initial cost of rock."

Laboratory and Service Tests of Rock. In order to ascertain the value of any rock as a material suitable for highway building, there are several tests that have been developed which give some indication as to what may be expected of a rock when used in the road. The tests are made to determine certain specific characteristics, and altho the results of the tests do not always agree with the results obtained in service tests, still they are a great aid in comparing the respective qualities of different rocks. There are many variable conditions to which a road is subjected, and since it is difficult to duplicate these conditions by any accelerated mechanical test, the best knowledge in regard to the worth of any rock will be obtained from observations of its wear in actual service. Tests are made to determine the physical properties of abrasion, cementing value, toughness, hardness, crushing strength, absorption, and specific gravity.

The Methods of Testing Rock and Broken Stone given herewith are those adopted by the Special Committee on "Materials for Road Construction" of the Am. Soc. C. E., designated Am. Soc. C. E. Method; those proposed by Committee D-4, "Standard Tests for Road Materials" of the Am. Soc. Test. Mat., designated Am. Soc. Test. Mat. Com. D-4 Method; and those adopted by the Am. Soc. Test. Mat., designated Am. Soc. Test. Mat. Method.

Mechanical Analysis of Broken Stone. See Sect. 10, Art. 7.

Voids in Broken Stone. See Sect. 10, Art. 7.

Specific Gravity of Coarse Aggregates. Am. Soc. Test. Mat. Com. D-4 Method. "The apparent specific gravity shall be determined in the following manner: The sample, weighing 1000 g and composed of pieces approximately cubical or spherical in shape and retained on a screen having 1.27-cm (½-in) circular openings, shall be dried to constant weight at a temperature between 100° and 110° C (212° and 230° F), cooled, and weighed to the nearest 0.5 g. Record this weight as weight *A*. In the case of homogeneous material, the smallest particles in the sample may be retained on a screen having 1¼-in circular openings.

"Immerse the sample in water for 24 hr, surface-dry individual pieces with aid of a towel or blotting paper, and weigh. Record this weight as weight *B*. Place the sample in a wire basket of approximately ¼-in mesh, and about 12.7 cm (5 in) square and 10.3 cm (4 in) deep, suspend in water* from center of scale pan, and weigh. Record the difference between this weight and the weight of the empty basket suspended in water as weight *C*, weight of saturated sample immersed in water.

"The apparent specific gravity shall be calculated by dividing the weight of the dry sample *A* by the difference between the weights of the saturated sample in air *B* and in water *C*, as follows:

$$\text{APPARENT SPECIFIC GRAVITY} = \frac{A}{B - C}.$$

"Attention is called to the distinction between apparent specific gravity and true specific gravity. Apparent specific gravity includes the voids in the specimen and is therefore always less than or equal to, but never greater than the true specific gravity of the material."

Apparent Specific Gravity of Sand, Stone Screenings, or Other Fine Highway Material. Am. Soc. C. E. Method.

"APPARATUS. The determination shall be made with a Jackson specific gravity apparatus which shall consist of a burette, with graduations reading to 0.01 in specific gravity, about 23 cm (9 in) long and with an inside diameter of about 0.6 cm (0.25 in), which shall be connected with a glass bulb approximately 13 cm (5.5 in) long and 4.5 cm (1.75 in) in diameter, the glass bulb being of such size that from a mark on the neck at the top to a mark on the burette just below the bulb, the capacity is exactly 180 cc (6.09 oz); and an Erlenmeyer flask, which shall contain a hollow ground-glass stopper having the neck of the same bore as the burette and a capacity of exactly 200 cc (6.76 oz) up to the graduation on the neck of the stopper.

"METHOD OF DETERMINATION. The method shall consist of: (1) dry at not more than 110° C (230° F) to a constant weight a sample weighing about 55 g; (2) weigh to 0.1 g, 50 g of the dry sample and pour it into the unstoppered Erlenmeyer flask; (3) fill the bulb and burette with kerosene, leaving just space enough to take the temperature by introducing a thermometer thru the neck; (4) remove the thermometer and add sufficient kerosene to fill exactly to the mark on the neck, drawing off any excess with the burette; (5) run into the flask about one-half of the kerosene in the bulb to remove air bubbles and then run in more kerosene, removing any material adhering to the neck of the flask, until the kerosene is just below the ground glass; (6) place the hollow ground-glass stopper in position and turn it to fit tightly, and then run in kerosene exactly to the 200-cc (6.76-oz) graduation on the neck, care being taken to remove all air bubbles in the flask; (7) read the specific gravity from the graduation on the burette, and the temperature of the oil in the flask, noting the difference between the temperature of the oil in the bulb before the determination and that of the oil in the flask after the determination; (8) make a temperature correction to the reading of the specific gravity in accordance with the table furnished by the manufacturer of the apparatus, adding the correction if the temperature of the kerosene has increased and subtracting it if the temperature of the kerosene has decreased."

*The basket may be conveniently suspended by means of a fine wire hung from a hook shaped in the form of a question-mark with the top end resting on the center of the scale pan.

Absorption of Water Per Cubic Foot of Rock. Am. Soc. Test. Mat. Com. D-4 Method.

"The absorption of water per cubic foot of rock shall be determined by the following method: (1) a sample weighing between 29 and 31 g and approximately cubical in shape shall be dried in a closed oven for 1 hr at a temperature of 110° C (230° F) and then cooled in a desiccator for 1 hr; (2) the sample shall be rapidly weighed in air; (3) trial weighings in air and in water of another sample of approximately the same size shall be made in order to determine the approximate loss in weight on immersion; (4) after the balances shall have been set at the calculated weight, the first sample shall be weighed as quickly as possible in distilled water having a temperature of 25° C (77° F); (5) allow the sample to remain 48 hr in distilled water maintained as nearly as practicable at 25° C (77° F) at the termination of which time bring the water to exactly this temperature and weigh the sample while immersed in it; (6) the number of pounds of water absorbed per cubic foot of the sample shall be calculated by the following formula:

$$\text{POUNDS OF WATER ABSORBED PER CUBIC FOOT} = \frac{W_2 - W_1}{W - W_1} \times 62.24$$

in which W represents the weight in grams of sample in air; W_1, the weight in grams of sample in water just after immersion; W_2, the weight in grams of sample in water after 48 hours' immersion, and 62.24, the weight in pounds of a cubic foot of distilled water having a temperature of 25° C (77° F).

"Finally, the absorption of water per cubic foot of the rock, in pounds, shall be the average of three determinations made on three different samples according to the method above described."

Abrasion Test for Broken Stone. Am. Soc. Test. Mat. Method.

"The machine (see Fig. 1) shall consist of one or more hollow iron cylinders; closed at one end and furnished with a tightly fitting iron cover at the other; the cylinders to be 20 cm (7.87 in) in diameter and 34 cm (13.38 in) in depth, inside. These cylinders are to be mounted on a shaft at an angle of 30° with the axis of rotation of the shaft.

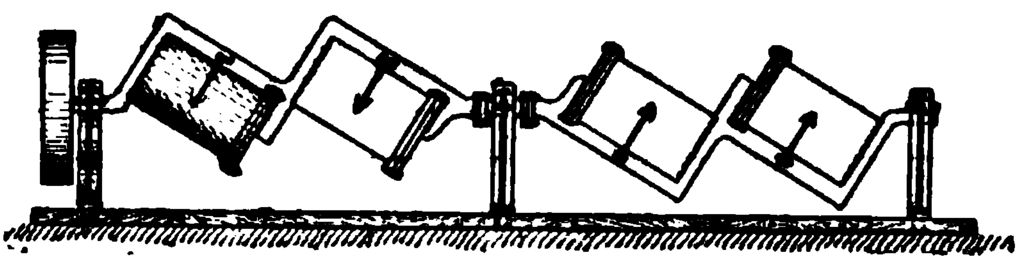

Fig. 1. Deval Abrasion Machine

"At least 13.6 kg (30 lb) of coarsely broken stone shall be available for a test. The rock to be tested shall be broken in pieces as nearly uniform in size as possible, and as nearly 50 pieces as possible shall constitute a test sample. The total weight of rock in a test shall be within 10 g of 5 kg (11.02 lb). All test pieces shall be washed and thoroly dried before weighing. Ten thousand revolutions, at the rate of between 30 and 33 to the minute, must constitute a test. Only the percentage of material worn off which will pass thru a 0.16-cm ($\frac{1}{16}$-in) mesh sieve shall be considered in determining the amount of wear."

French Coefficient of Wear equals 40 divided by the percent of wear.

Modified Abrasion Test by Scofield (39). "The principle of action of the machine is that of the brick rattler in that its sides are straight metal pieces with spaces between to allow for the escape of the dust. Its cross-section is octagonal and its internal volume was made equal to that of the Deval cylinder. Its length is also the

same as that of the Deval cylinder. The space between the staves or sides of the chamber is ¼-in, allowing for free passage of dust and particles up to that size.

"It was the purpose, at first, to use this abrasion chamber in a Deval frame so that the motion and movement of the charge would be similar to that in the regular test, but later in order to make a simpler and more compact machine, it was so arranged that it revolved about its own longitudinal axis in a horizontal position. It was also thought that, operated in this latter position, it would be necessary to employ an abrasive charge as in the standard brick rattler test, in order to give an appreciable loss during the test. This was erroneous, however, as the results show.

"The number of comparative tests already made with this machine are not many, but the results seem to be conclusive and show that the cushioning effect of the dust is very marked.

"The following tests have been made upon two limestones of very great difference in hardness: (1) Both stones in the regular Deval test; (2) both stones with new type of chamber in a Deval frame; (3) both stones with new type of chamber with its axis horizontal and with an abrasive charge consisting of a small amount of 1-in and ½-in tempered steel balls; (4) both stones with new type of chamber with its axis horizontal and no abrasive agent; (5) both stones in a regular Deval test except that the stones and inside of cylinder were given a thoro dry cleaning after every 1000 revolutions, thus reducing cushioning effect to a much smaller degree.

"The results of tests of a hard and soft stone with the two types of abrasive chambers follow:

Kind of Test	Percent Wear		
	Monon Limestone	Bedford Limestone	Ratio
1. Deval test regular	5.3	10.3	1.95
2. New type Deval frame	12.8	52.6	4.12
3. New type, horizontal with abrasive agent	12.8	37.7	2.94
4. New type, horizontal with no abrasive agent	12.3	35.3	2.87
5. Deval test with all dust removed after every 1000 rev	10.7	25.8	2.41

"In the new type of chamber practically all of the dust is removed as fast as formed. That this has a great effect is shown in items (1) and (2) in above table. In the case of the hard stone the removal of the dust caused only about 140% increase in the percent wear, but in the case of the soft stone, it caused 410% increase.

"Altho more tests are needed to establish the facts, it would seem that the following conclusions can be drawn from the above tests: To remove the dust in a testing machine of this kind is the correct principle and prevents the boosting of an inferior stone in comparison with a good one. The new type gives a wider range of values for a given lot of stones and therefore better differentiation of quality. The new type operating on a horizontal axis is a more simple and compact machine, and of cheaper construction."

Cementation of Rock, Slag, and Gravel Powders. Am. Soc. C. E. Method. " The cementation test shall be made as follows: Of the material to be tested, 500 g shall be broken to pass a 1.27-cm (½-in) mesh sieve and then placed in a ball mill (see Fig. 2) with 90 cc (3.02 oz) of water and two steel shot weighing together 9 kg (20 lb). The mill and its charge shall be revolved for 2½ hr at a rate of 2000 rev per hr. The dough thus formed shall then be removed, and 25 g of an average sample of it shall be placed in a metal die, 25 mm (0.98 in) in diameter, and subjected to a pressure of 132 kg per sq cm for an instant in a hydraulic press. The cylindrical briquette resulting should measure exactly 25 mm (0.98 in)

in height. If it does not, subsequent samples of the dough shall be taken in such quantity that the resulting briquette after compression will be exactly 25 mm (0.98 in) in height. Five such briquettes shall be made and allowed to dry in the air for a period of 20 hr, after which they shall be heated for 4 hr in a hot-air oven at a temperature of 93.3° C (200° F), and then cooled in a desiccator for 20 min. These cylinders or briquettes shall then be tested in a machine as follows:

"The machine shall be arranged so that a 1-kg (2.20 lb) hammer is raised to a height of 1 cm (0.39 in), and then falls freely on a plunger, transmitting the shock of the blows of the hammer thru the plunger to the test piece, successive blows being struck by the hammer at a rate of 40 to 70 per min, until the test piece fails, which is indicated by the failure of the plunger or hammer to rebound. The test piece shall be placed on the anvil under the plunger without lateral support, and may be fastened in place on the anvil by a drop of shellac. The average of the number of blows on the five briquettes, required to produce failure in each case, is the result to be reported, and is the coefficient of cementation."

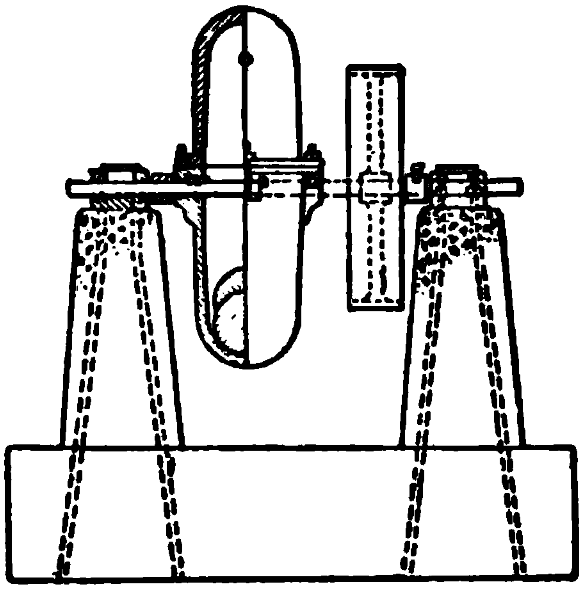

Fig. 2. Ball Mill

Test for Toughness of Rock. Am. Soc. Test. Mat. Com. D-4 1918 Method.

"Definition. Toughness, as applied to rock, is the resistance offered to fracture under impact, expressed as the final height of blow required of a standard hammer to cause fracture of a cylindrical test specimen of given dimensions.

"Sampling. Quarry samples of rock from which test specimens are to be prepared shall measure at least 6 in on a side and at least 4 in in thickness, and when possible shall have the plane of structural weakness* of the rock plainly marked thereon. Samples should be taken from fresh quarried material, and only from pieces which show no evidences of incipient fracture due to blasting or other causes. The samples should preferably be split from large pieces by the use of plugs and feathers and not by sledging. Commercial stone block samples from which test specimens are to be prepared shall measure at least 3 in on each edge.

"Size and Form of Test Specimen. Specimens for test shall be cylinders, 25 mm in height and from 24 to 25 mm in diameter. Three test specimens shall constitute a test set. The ends of the specimen shall be plane surfaces at right angles to the axis of the cylinder.

"Preparation of Test Specimens. One set of specimens shall be drilled perpendicular and another parallel to the plane of structural weakness of the rock, if such plane is apparent. If a plane of structural weakness is not apparent, one set of specimens shall be drilled at random. Specimens shall be drilled in a manner which will not subject the material to undue stresses and which will insure the specified dimensions.† The ends

*The plane of structural weakness may in certain cases be the rift, cleavage, or bedding plane.

†The form of diamond drill described in Bul. No. 347, U. S. Dep. Agr., pp. 6 and 7, is recommended, and should prove satisfactory if the instructions are strictly followed.

of the cylinders may be sawed by means of a band or diamond saw,* or in any other way which will not induce incipient fracture, but shall not be chipped or broken off with a hammer. After sawing, the ends of the specimens shall be ground plane with water, and carborundum or emery on a cast-iron lap until the cylinders are 25 mm in length.

"IMPACT MACHINE. Any form of impact machine which will comply with the following essentials may be used in making the test:

1. A cast-iron anvil weighing not less than 50 kg, firmly fixed upon a solid foundation;

2. A hammer weighing 2 kg, arranged so as to fall freely between suitable guides;

3. A plunger made of hardened steel and weighing 1 kg, arranged to slide freely in a vertical direction in a sleeve, the lower end of the plunger being spherical in shape with a radius of 1 cm;

4. Means for raising the hammer and for dropping it upon the plunger from any specified height from 1 to not less than 75 cm, and means for determining the height of fall to approximately 1 mm;

5. Means for holding the cylindrical test specimen securely on the anvil without rigid lateral support, and under the plunger in such a way that the center of its upper surface shall, thruout the test, be tangent to the spherical end of the plunger at its lowest point.

"METHOD OF TESTING. The test shall consist of a 1-cm fall of the hammer for the first blow, a 2-cm fall for the second blow, and an increase of 1-cm fall for each succeeding blow until failure of the test specimen occurs.

"RECORDING AND REPORTING RESULTS. The height of the blow in centimeters at failure shall be the toughness of the test specimen. The individual and the average toughness of three test specimens shall be reported when no plane of structural weakness is apparent. In cases where a plane of structural weakness is apparent, the individual and average toughness of the three specimens in each set shall be reported and identified. Any peculiar condition of a test specimen which might affect the result, such as the presence of seams, fissures, etc. shall be noted and recorded with the test result."

Effect of Controllable Variables on the Toughness Test for Rock by Jackson (27):

"1. In judging the quality of a rock quarry from the results of a single test, the fact that large variations in toughness may occur from time to time should be borne in mind, and an effort made to secure a test of the material at approximately the same time that the material is to be used.

"2. Great care should always be exercised in selecting samples for the toughness test, because the product of a rock quarry of even apparently uniform quality is apt to vary, thruout different portions of the face.

"3. In preparing samples for the toughness text, the following points should be kept in mind and the operator governed accordingly: (a) In every case where planes of foliation as in all gneisses and schists, or planes of bedding as in many sandstones and some limestones, are visible, specimens should be drilled as nearly at right angles to the plane of weakness as possible. Another set of specimens should also be prepared from samples drilled parallel to the plane of weakness; (b) no core drill should be used which drills specimens with a greater total variation than 1 mm; (c) variations in the height of specimens may be as great as 1 mm without practically affecting the result; (d) variations in the moisture content of specimens apparently do not practically affect the result, but for the sake of uniformity all specimens should be dried in an oven prior to testing; and (e) the greatest possible care should be exercised in the preparation of the specimen, so as to insure perfect bearing surfaces absolutely perpendicular to the axis of the cylinder.

*A satisfactory form of diamond saw is described in Bul. No. 347, U. S. Dept. Agr., pp. 7 to 9.

"4. Very little injury is done to a specimen during the progress of the test as a result of vibrations of the plunger.

"5. The total energy of the blow required to cause failure is not influenced by secondary blows of the hammer, produced by its rebound after striking the plunger."

Hardness Test for Rock or Slag. Am. Soc. C. E. Method. "The test for hardness shall be made with a Dorry (see Fig. 3), or similar machine, consisting of a revolving disk on which is fed, at a uniform rate, a standard quartz sand passing a 30 and retained on a 40-mesh sieve. Two cores, each 25 mm (0.98 in) in diameter, shall be cut from the material to be tested, and their faces ground off so as to be at right angles to the long axes of the cores. The cores shall be placed in the holders or dies and weighted so that the entire weight of each core with its holder and added weight is 1250 g. Each core shall be ground in the machine on one face for 1000 rev, after which it shall be reversed and ground on the other face for an equal number of revolutions. The loss of weight of each specimen shall be determined at the end of each 1000 rev, and the average loss in weight shall be used for stating the hardness of the material, which latter shall be expressed by the formula: HARDNESS $= 20 - \frac{1}{3} W$, where W equals the average loss in grammes per 1000 rev."

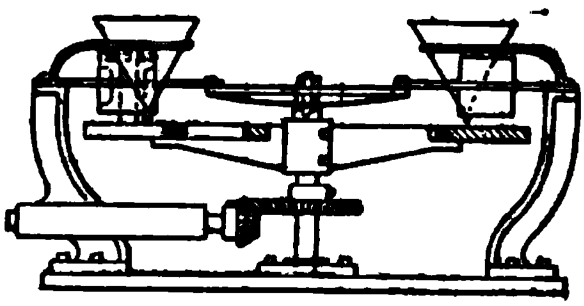

Fig. 3. Dorry Hardness Machine

Crushing Strength of Rock or Slag. Am. Soc. C. E. Method. "Cylinders shall be cut from a suitable block of the material to be tested, each of which cylinders shall, as nearly as practicable, be 5 cm (2 in) in diameter and 10 cm (4 in) in length. After cutting, the dimensions of each cylinder shall be accurately measured and recorded. Each cylinder shall then be subjected to compression, and the ultimate stress at which its failure occurs shall be noted. This stress divided by the average area in cross-section of the cylinder in square inches shall be reported. It is desirable that the test of the material shall be made on at least three such cylinders separately, and the average of the three or more specimens shall be taken as the average resistance to crushing of the material. In making the test, the cylinder shall be fixed in the testing machine so as to be unsupported on its sides and rest squarely on its ends, and the compressive stress shall be applied cumulatively. The ends of the cylinder shall be at right angles to its long axis, and the blocks or pieces of the machine in contact with the ends of the cylinder and thru which the pressure is transmitted shall have such position and freedom of movement in the machine as will insure the application of the stress directly along or parallel to the long axis of the cylinder."

Results of Tests on Rock Samples, as made by the U. S. O. P. R., are given in Tables II and V.

Variations in the Properties of Road-Building Rocks (42). The chart, shown in Fig. 4, shows in graphic form the variations which have been found to exist in the French coefficient of wear, toughness, and hardness of 4 of the road-building rock families. In each of the blocks shown on the chart the horizontal scale represents the range in test values beginning at 0 on the left and numerically increasing toward the right. The vertical scale in each case shows percentages of the total number of samples tested. Each of the heavy black vertical lines, therefore, represents the percentages of the total number of samples of the type indicated having a value corresponding to that shown on the horizontal base line immediately below it. This chart is primarily of value in enabling the results of a particular test to be compared

Table II.—Maximum and Minimum Results on Rock Samples, Corrected to Jan. 1, 1915

No. of Samples	Name	Specific Gravity			Weight Lb per Cu Ft			Water Absorbed, Lb per Cu Ft		Percent of Wear		French Coefficient of Wear		Hardness		Toughness		Cementing Value	
		Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
24	Amphibolite	3.15	2.75	3.03	196	172	189	1.65	0.04	10.3	1.5	41.7	3.9	19.0	13.5	40	7	235	3
60	Andesite	2.95	1.85	2.66	184	115	166	12.50	0.05	17.4	1.4	28.6	2.3	19.4	5.0	44	5	500	9
210	Basalt	3.20	2.30	2.85	199	143	178	6.40	0.02	16.6	1.3	30.4	2.4	19.3	5.7	47	5	500	2
67	Chert	3.00	2.00	2.54	187	125	158	8.27	0.25	29.2	2.7	33.3	1.4	19.7	12.7	26	3	500	2
13	Conglomerate	2.75	2.50	2.60	172	156	162	3.31	0.36	26.8	3.5	11.6	1.5	18.4	9.3	10	10	500	4
289	Diabase	3.20	2.65	2.94	200	165	185	2.73	0.04	6.3	1.1	26.4	6.4	19.4	10.7	54	4	500	2
85	Diorite	3.35	2.70	2.88	209	168	179	1.00	0.05	12.0	1.7	23.8	3.3	19.4	16.6	38	4	164	5
414	Dolomite	3.00	2.30	2.72	187	143	173	9.40	0.07	22.5	1.2	33.3	1.8	18.8	0.5	27	2	317	8
9	Eclogite	3.70	2.95	3.15	231	184	196	0.28	0.05	2.9	1.8	22.7	13.8	18.8	17.4	31	14	130	10
13	Epidosite	3.30	2.70	3.00	206	168	187	1.65	0.22	7.4	2.0	19.6	5.4	19.5	10.7	29	18	83	3
12	Felsite	2.85	2.50	2.65	178	156	165	3.13	0.02	3.4	1.9	21.3	11.8	18.7	18.7	16	16	101	2
91	Fieldstone	....	....	....	....	....	....	....	....	10.3	2.1	19.0	3.8	....	....	....	....	....	....
50	Gabbro	3.65	2.75	2.97	228	172	185	2.62	0.04	5.9	1.3	30.8	6.8	18.8	13.3	23	6	325	5
221	Gneiss	3.20	2.60	2.76	200	162	172	1.28	0.02	16.4	1.7	29.0	2.4	19.5	9.0	26	2	209	1
312	Granite	3.00	2.00	2.66	187	125	166	3.00	0.04	24.6	1.1	37.0	1.6	19.7	13.6	33	2	255	2
372	Gravel	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	500	1
1032	Limestone	2.85	2.00	2.67	178	125	167	13.22	0.02	34.2	1.8	21.7	1.2	19.2	0.0	25	2	500	8
74	Marble	2.90	2.65	2.77	181	165	173	2.19	0.06	27.0	2.3	17.5	1.5	17.3	4.5	23	2	85	9
16	Marl	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	500	6
19	Mixed Stone	....	....	....	....	....	....	....	....	10.3	2.1	19.1	3.9	....	....	....	....	....	....
5	Peridotite	3.55	2.65	2.95	221	165	184	1.02	0.27	5.3	3.0	13.2	7.6	15.0	13.3	12	9	91	25
135	Quartzite	3.15	2.15	2.69	196	147	175	2.95	0.04	7.6	1.6	24.5	5.3	19.7	15.3	58	4	200	0
48	Rhyolite	2.90	2.05	2.57	181	128	160	7.15	0.03	9.7	1.7	24.1	4.1	19.7	15.3	42	6	500	1
465	Sandstone	3.25	1.90	2.61	203	119	163	14.00	0.07	43.9	1.0	40.8	1.0	19.5	0.0	60	2	500	1
193	Schist	3.20	2.50	2.89	200	156	183	1.87	0.06	23.3	1.3	31.7	1.7	19.2	0.9	44	3	232	5
17	Shale	2.75	2.50	2.68	172	156	167	4.80	0.50	35.2	3.2	12.6	1.1	17.7	13.9	12	3	368	28
70	Slag	3.90	2.00	2.89	243	125	182	4.90	0.04	19.1	2.3	17.7	2.1	18.8	9.5	21	2	500	1
85	Slate	3.80	2.40	2.77	209	150	172	3.41	0.05	17.1	1.6	24.4	2.3	19.7	1.1	56	1	255	1
32	Syenite	3.05	2.15	2.75	190	134	172	3.06	0.05	14.4	1.6	25.6	2.8	19.2	16.4	22	7	375	2
1	Travertine	2.70	2.70	2.70	168	168	168	0.065	0.065	5.9	5.9	6.8	6.8	12.0	12.0	4	4	24	24

with all others which have been made by the Office on similar material. Thus, suppose the results of tests on a certain sample of limestone showed a French coefficient of wear of 11, a toughness of 10, and a hardness of 17.5. By referring to the limestone block it is seen that 5.5% of 793 limestones showed a French coefficient of wear of 11, 7.5% of 839 have a toughness of 10, and 5% of 826 have a hardness of 17.5. The chart shows, furthermore, that a large majority of all limestones have values ranging lower than those cited in the example, or, in other words, that this

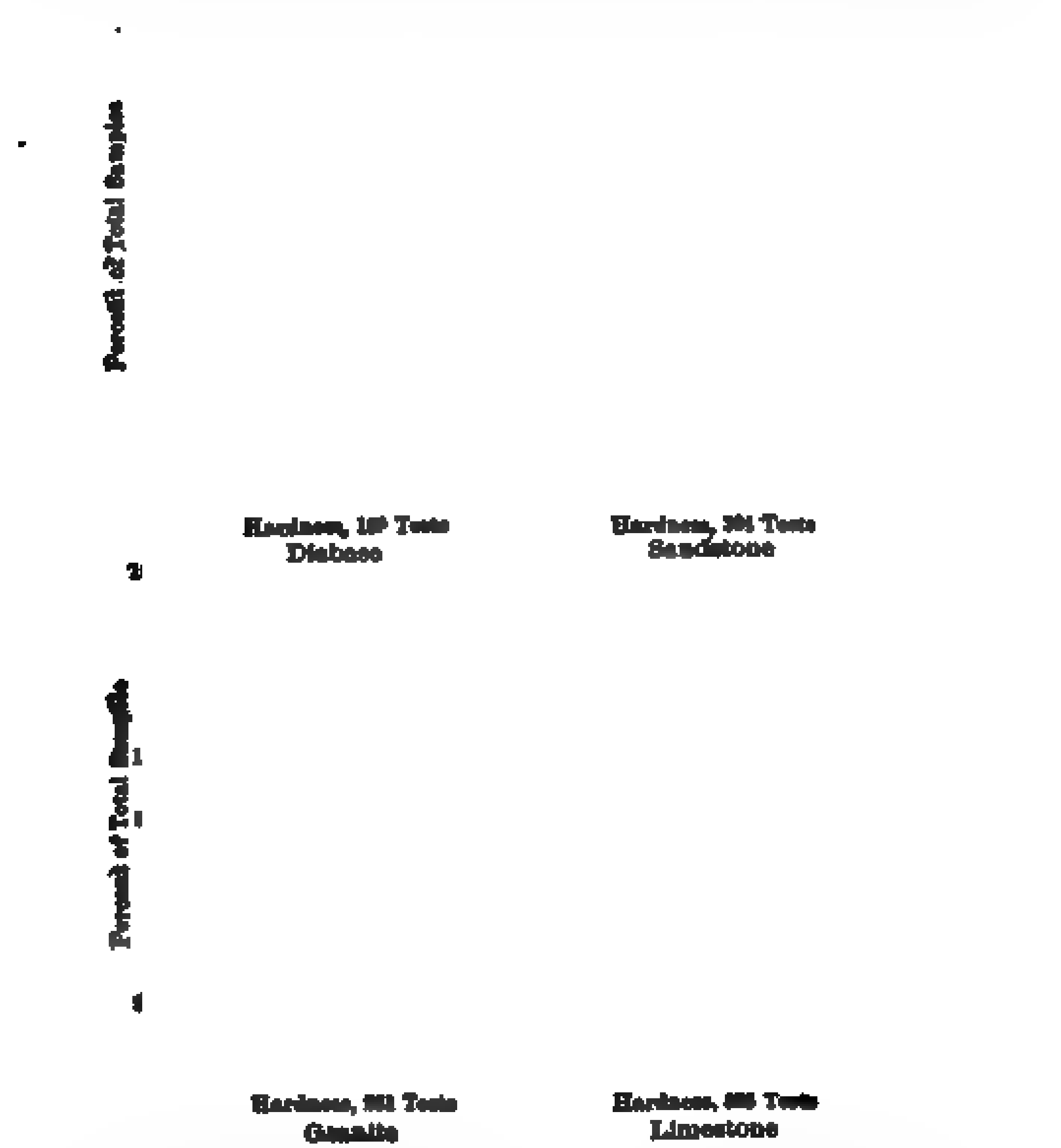

Fig. 4. Variations in Physical Properties of Road Building Rocks

limestone is considerably above the average on all of the three determinations shown on the chart. The exact percentages either above or below may, of course, be calculated by taking the sum of all the vertical lines lying to the right or left of the value which are considered.

Interpretation of Results of Tests on Rock Samples by U. S. O. P. R. (42). Results of about 2700 determinations indicate that in general the limits in Table III for low, average, and high values for each of the tests may be applied:

Table III.

Tests	Low	Average	High
French coefficient of wear	Under 8	8 to 12	Over 12
Toughness	Under 8	8 to 12	Over 12
Hardness	Under 15	15 to 18	Over 18
Cementing value	Under 25	25 to 75	Over 75

For a more complete discussion of the relation between the results of laboratory and service tests, see (25a).

Table IV.—General Limiting Test Values for Broken Stone (25b)

Type of Construction	Traffic*	Limiting Values		
		French Coefficient of Wear	Toughness	Hardness
Water-bound macadam, plain or with dust palliative treatment	Light	5 to 8	5 to 9	10 to 17
	Moderate	9 to 15	10 to 18	14 or over
	Heavy	16 or over	19 or over	17 or over
Macadam with bituminous carpet	Light to Moderate	5 or over	5 or over	(†)
Bituminous macadam with seal coat	Moderate to heavy	7 or over	10 or over	....
Bituminous concrete	Light to Moderate	7 or over	7 or over	(†)
	Moderate to Heavy	10 or over	13 or over	....
Binder course for sheet-asphalt or Topeka type	Any	7 or over	6 or over	(†)
Portland cement-concrete	Moderate to Heavy	(‡)	8 or over	16 or over
Stone paving block§	Any	(‡)	9 or over	16 or over
Broken stone foundation	Any	3 or over	3 or over	8 or over

*Light traffic is assumed as less than 100 vehicles per day, moderate traffic between 100 and 250 vehicles, and heavy traffic over 250 vehicles per day.

†Numerous tests have shown that limits for hardness are unnecessary if the material possesses the required French coefficient of wear and toughness.

‡Limits for French coefficient of wear are not at present considered necessary for this type of construction.

§Crushing strength, 20 000 lb or over per sq in is sometimes required.

"Cementing Values should show over 25 in all cases if material is to be used in water-bound macadam construction. In general, granites, gneisses, schists, sandstones, and quartzites should not be used in the wearing course of water-bound macadam roads. Shales and slates never should be used in this connection; therefore cementing value tests have been discontinued on these materials."

6. Sizes of Broken Stone

The sizes of broken stone to be used in each course are dependent upon the quality of the stone, the nature of traffic and economy. If the stone is not hard the larger sizes of stone should form a large percentage of the upper course, unless the roadway is designed for light pleasure travel, in

Table V.—Results of Compression Tests of Rock (25b)

Name of Rock	Crushing Strength Lb per Sq In	Locality	County	State
Biotite gneiss	14 585	Gloversville	Fulton	N. Y.
Limestone	16 000	Greencastle	Putnam	Ind.
Limestone	17 580	Frederick	Frederick	Md.
Limestone	27 500	Walford	Lawrence	Pa.
Argillaceous dolomite	15 730	Hillside	Cook	Ill.
Dolomite	17 960	Greensburg	Decatur	Ind.
Argillaceous dolomite	11 750	Monroe	Monroe	Mich.
Sandstone	29 000	Albion	Orleans	N. Y.
Calcareous sandstone	9 490	Clarksfield	Huron	Ohio
Feldspathic sandstone	26 340	Prompton	Wayne	Pa.
Ferruginous sandstone	17 780	Nokesville	Prince Wm.	Va.
Feldspathic sandstone	11 910	Parkersburg	Wood	W. Va.
Biotite granite	16 635	Oneco	Windham	Conn.
Granite	21 260	North Jay	Franklin	Me.
Granite	20 020	Vinal Haven	Knox	Me.
Granite	17 540	Long Cove	Knox	Me.
Biotite granite	22 370	Rockport	Essex	Mass.
Granite	13 980	Westford	Middlesex	Mass.
Granite	14 150	Alexandria Bay	Jefferson	N. Y.
Granite	16 200	Yorktown	Westchester	N. Y.
Granite	15 615	Marlboro	Cheshire	N. H.
Granite	13 420	Concord	Merrimack	N. H.
Granite	16 440	Mt. Airy	Surry	N. C.
Granite	20 750	Westerly	Washington	R. I.
Altered diabase	32 850	Westfield	Hampden	Mass.
Altered diabase	39 215	Birdsboro	Berks	Pa.
Feldspathic quartzite	16 500	Greenway	Nelson	Va.

which case the smaller sizes should be used for the top course, as this will tend to produce a smooth and desirable surface. With any quality of stone, traffic consisting of heavy vehicles is less destructive to the road surface if the larger sizes are placed in the upper course. For economical consideration it is often desirable, especially where the stone is crushed locally, to so distribute the sizes in the courses that the entire product of the crusher may be used.

The percentage of each size of output from a crusher varies with the quality of the stone. In general, the softer the stone the greater will be the proportion of fine material, but no fixed formula can be adopted. A crusher set with the jaws at 2½ in may produce with a granite of medium hardness 30 to 40% of stone from 1¼ to 2½ in in size, 30 to 40% from ½ to 1¼ in and 25 to 35% of material under ½ in in size, or an average of 35, 35 and 30% of the above respective sizes. With a trap rock the same crusher opening would produce an average of approximately 50, 30 and 20% of these sizes.

In preparing specifications for sizes of stone, it is quite necessary to state the limitations in sizes either by size of apertures of screens or by size of ring thru which stones will or will not pass. The safest method is by the size of rings, but the most common method is by the size of screen apertures. If a specification simply states that "no stone shall be used except that which will pass thru a screen whose apertures measure 2½ in in diameter, but will not pass thru a screen whose apertures measure 1¼ in in diameter," then the product obtained may contain an excess of material that will pass thru a 1¼-in ring, on account of the fact that if the cylindrical screens

are too small for the output of the crusher, or are set at too great an angle or are revolved too rapidly, the small sizes will pass along instead of thru the smaller screens and be deposited with the larger sizes. Designation of sizes as No. 1, chestnut, or other similar designations should never be used unless such designations are clearly described by dimensions or by reference to some well-known standard. As an illustration of the fallacy of such designations, No. 1 size stone in Massachusetts corresponds practically with No. 3 size in the adjoining state of New York.

Variations in Products of Broken Stone (11a). "Products of broken stone obtained from portable and stationary stone-crushing and screening plants, while complying with a given specification of the type now ordinarily used, vary to a considerable extent, due to variations in the plant and its operation, such as kind of rock, type and method of operation of crushing plants, methods of separation of products, differences in lengths and diameters of sections of rotary and shaker screens, and differences in inclination and rate of operation of screens.

"The necessity for more carefully drawn specifications covering the sizes of the particles of which a given product of a stone-crushing and screening plant is composed, is illustrated by the following mechanical analyses of two products obtained from the same plant, both of which products passed over a section of a rotary screen having circular holes 1¼ in and thru a section of a rotary screen having circular holes 2¼ in in diameter.

	Sample A Percentage	Sample B Percentage
Passing ¼-in screen	0.3	0.2
Passing ½-in screen and retained on ¼-in screen	0.4	1.1
Passing ¾-in screen and retained on ½-in screen	2.2	12.6
Passing 1-in screen and retained on ¾-in screen	8.0	37.5
Passing 1¼-in screen and retained on 1-in screen	29.1	40.9
Passing 1½-in screen and retained on 1¼-in screen	27.1	7.7
Passing 2-in screen and retained on 1½-in screen	32.9	0.0
	100.0	100.0"

Proportions of Products of Broken Stone (22) at crushing plants in New York are given in the following table. For specifications covering the sizes of broken stone, see Art. 10.

Reference Number	Cu Yd Field Stone Delivered to Crusher	Cu Yd Crushed Stone Produced	No. 1		No. 2		No. 3		No. 4		Kind of Material
			Cu Yd				Cu Yd Produced	Percent of Total Output	Cu Yd Produced	Percent of Total Output	
1.	196	190	36	19	18	9	64	34	72	38	Sandstone and limestone
2.	187	182	32	17½	10	5½	70	28½	70	38½	Limestone
3	196	202	36	18	14	7	76	38	76	37	Limestone and sandstone
4	190	216	40	18	18	8	79	37	79	37	Sandstone
5	173	172	32	19	28	16	62	36	50	29	Poor sandstone
6	189	184	36	19½	16	9			132	71½	Limestone
7	165	170	32	19	22	13			116	68	Limestone

7. Specifications for Broken Stone

Am. Soc. C. E. and Am. Soc. Test. Mat. (11a) recommendations of the Spec. Com. Mat. Road Cons. and Com. D-4, Standard Tests for Road Materials, respectively.

"The broken stone shall consist of one product of the operation of a stone-crushing and screening plant, without recombining or mixing, and shall conform to the following mechanical analysis, using laboratory screens:

Passing ...... in screen, having smallest holes selected, from	...... to ......%
Passing ...... in screen, having next to largest holes selected, from	...... to ......%
Passing ...... in screen, having largest holes holes selected, from	...... to ......%

"In this form of specification an attempt is made to cover in the mechanical analysis only the limits of the smallest and largest particles. No attempt is made to secure a carefully graded aggregate, but simply a product suitable for the type of road or pavement in question.

"Note: An engineer should base the selection of screens, to be used in the specification for a given product of broken stone, on the results of mechanical analyses of many similar products obtained from portable and stationary crushing and screening plants which supply the locality in which the specification is to be used.

"Example. The broken stone shall consist of one product of the operation of a stone-crushing and screening plant without recombining or mixing, and shall conform to the following mechanical analysis, using laboratory screens:

Passing ¼-in screen	8 to 10%
Passing 1 -in screen and retained on ¼-in screen	80 to 95%
Passing 1¼-in screen and retained on 1-in screen	2 to 10%
Total passing 1¼-in screen	100%."

Am. Soc. Mun. Imp. (12). "QUALITY OF BROKEN STONE. All broken stone shall be clean, rough surfaced and sharp angled, of compact texture and uniform grain.

"TESTS FOR BROKEN STONE. The broken stone shall be subjected to abrasion tests and toughness tests conducted by the Engineer in accordance with methods adopted by the Am. Soc. Test. Mat., August 15, 1908. It shall show a French coefficient of wear of not less than 7.0 and its toughness shall be not less than 6.0.

"SIZES. The product of the crusher shall be passed over a rotary screen with sections having respectively circular openings of the following dimensions: First section, ⅝-in holes; second section, 1¼-in holes; third section, 2¼-in holes; fourth section, 3½-in holes. If so directed the first section of the screen shall be fitted with a dust jacket having ¼-in openings so placed as to separate the dust from the product passing thru the first section. The screening plant shall also be fitted with a tailing chute so that no stone failing to pass the largest openings will fall into the bin for No. 4 size broken stone. The various sizes of broken stone shall be caught in separate bins, and shall be designated as follows:

Dust, all passing thru ¼-in screen.
Screenings, all passing thru ⅝-in screen.
No. 1 size, passing thru ⅝-in screen and over ¼-in screen.
No. 2 size, passing over ⅝-in screen and thru 1¼-in screen.
No. 3 size, passing over 1¼-in screen and thru 2¼-in screen.
No. 4 size, passing over 2¼-in screen and thru 3½-in screen.
Tailings, passing over 3½-in screen.

"PORTABLE PLANTS. Portable crushing and screening plants shall be operated as directed.

"STATIONARY PLANTS. If broken stone is to be supplied from stationary crushing and screening plants, the several sizes of broken stone shall not be used unless samples have been previously approved by the Engineer. The various sizes of broken stone furnished shall be substantially the same as the samples approved."

Can. Soc. C. E. (16). "DEFINITION. Crushed stone shall be bedded rock or boulders which have been broken by mechanical means into fragments of varying shapes and sizes. It shall not contain more than 10% by weight of soft or friable material. Material of which the particles are coated with dirt or have the edges worn off will not be accepted.

"WEATHERED STONE. No crushed stone shall be accepted which shows signs of being disintegrated or reduced in quality by the action of the weather.

"CRUSHER RUN. Crusher run shall be the product of the crusher, of which not more than 8% by weight shall pass a ¼-in opening.

"SIZES OF STONE. The following schedule of sizes shall be used, with the percentages of material larger than the maximum and smaller than the minimum openings respectively, as shown. The sizes of opening shall mean the diameter of circular openings in steel or iron plates. The percentages shall be determined by weight. The sizes of stone with the openings by which they are obtained are as follows:

Name of Size	Maximum Size of Opening in Inches	Maximum Percentage Retained by Maximum Size of Opening	Minimum Size of Opening in Inches	Maximum Percentage Passing Minimum Size of Opening
5 -in	5	3	4	8
4 -in	4	3	3	8
3 -in	3	3	2½	8
2½-in	2½	5	2	10
2 -in	2	5	1½	10
1½-in	1½	5	1	15
1 -in	1	5	½	15
½-in	½	7	¼	15

"SCREENINGS. Screenings shall be material all of which shall pass a ¼-in screen.

"MINERAL DUST. Mineral dust shall be finely pulverized stone of which not less than 80% by weight shall pass a 200-mesh sieve.

"TESTS ON STONE. In addition to fulfilling the foregoing requirements, crushed stone shall be classed into three grades, according to qualities which shall be determined by tests conducted in a properly equipped laboratory. The properties determined shall be: Coefficient of wear, toughness and absorption. Material meeting the requirements of any of the grades with respect to coefficient of wear and toughness but failing to meet the requirement with respect to absorption may, on consideration of the engineer, be classed with the higher grade.

"GRADES OF CRUSHED STONE. Crushed stone shall be classed under one of the following grades:

Grade A is a rock which has a toughness of not less than 18, a coefficient of wear of not less than 14, and an absorption of not more than 0.6 lb per cu ft.

Grade B is a rock which has a toughness of not less than 10, a coefficient of wear of not less than 7, and an absorption of not more than 1.0 lb per cu ft.

Grade C is a rock which has a toughness of not less than 7, a coefficient of wear of not less than 5, and an absorption of not more than 1.5 lb per cu ft.

Grade D is a rock that does not meet the requirements of any of the above grades and which may be used only on consideration by the engineer."

Engineering Standards Committee of Great Britain specifications for sizes of broken stone are as follows: "THREE-INCH GAGE BROKEN STONE. Broken stone specified as 3-inch gage shall all pass thru a 3-in ring and shall consist of the following percentages by weight: Not more than 15% passing thru a 2½-in ring in every direction; not less than 65% over 2½ in, and not exceeding 4 in, in greatest length by measurement; not more than 20% over 4 in in greatest length by measurement.

"TWO AND ONE-HALF INCH GAGE BROKEN STONE. Broken stone specified as 2½-in gage shall all pass thru a 2½-in ring, and shall consist of the following percentages by weight: Not more than 15% passing thru a 2-in ring in every direction; not less than 65% over 2 in, and not exceeding 3 in, in greatest length by measurement; not more than 20% over 3 in in greatest length by measurement.

"TWO-INCH GAGE BROKEN STONE. Broken stone specified as 2-in gage shall all pass thru a 2-in ring and shall consist of the following percentages by weight: Not more than 15% passing thru a 1½-in ring in every direction; not less than 65% over 1½

in, and not exceeding 2½ in, in greatest length by measurement; not more than 20% over 2½ in in greatest length by measurement.

"ONE AND ONE-HALF-INCH GAGE BROKEN STONE. Broken stone specified as 1½-in gage shall all pass thru a 1½-in ring, and shall consist of the following percentages by weight: Not more than 15% passing thru a 1-in ring in every direction; not less than 65% over 1 in and not exceeding 2 in, in greatest length by measurement; not more than 20% over 2 in in greatest length by measurement.

In the British specifications everything below 1 in is called chippings and is specified as follows:

"ONE-INCH CHIPPINGS must all be capable of passing thru a square hole of 1-in side, and at least 70% by weight must be retained by a sieve having square holes of ¾-in side.

"THREE-QUARTER-INCH CHIPPINGS must all be capable of passing thru a square hole of ¾-in side and at least 70% by weight must be retained by a sieve having square holes of ½-in side.

"HALF-INCH CHIPPINGS must all be capable of passing thru a square hole of ½-in side and at least 70% by weight must be retained by a sieve having square holes of ⅜-in side.

"THREE-EIGHTHS-INCH CHIPPINGS must all be capable of passing thru a square hole of ⅜-in side and at least 70% by weight must be retained by a sieve having holes of ¼-in side.

"QUARTER-INCH CHIPPINGS must all be capable of passing thru a square hole of ¼-in side and at least 70% by weight must be retained by a sieve having square holes of ⅛-in side.

"ONE-EIGHTH-INCH CHIPPINGS must all be capable of passing thru a square hole of ⅛-in side and at least 70% by weight must be retained by a sieve having square holes of 1/16-in side."

Form of Specification for Broken Stone recommended for adoption at the first conference of State Highway Testing Engineers and Chemists held at the U. S. O. P. R. in Feb. 1917.

"GENERAL. The broken stone shall consist of angular fragments of (Insert types allowable), of uniform quality thruout, free from thin or elongated pieces, soft or disintegrated stone, dirt, or other objectionable matter.

"PHYSICAL PROPERTIES. The stone shall meet the following requirements:

Percent of wear..............................	....	to	....
Or French coefficient..............................	....	to	....
*Toughness..............................	....	to	....
*Hardness..............................	....	to	....
*Absorption..............................	not more than		....

"SCREENINGS OR NO. ... STONE. That portion of the product of the crusher, including the dust of fracture, which, when treated by means of laboratory screens, will meet the following requirements:

Passing .... in screen..............................	100%
Total passing .... in screen..............................	...% to ...%

"TOP COURSE OR NO. ... STONE. That portion of the product of the crusher which, when tested by means of laboratory screens, will meet the following requirements:

Passing .... in screen..............................	100%
Total passing .... in screen..............................	...% to ...%
Retained on .... in screen..............................	100%

"BOTTOM COURSE OR NO. ... STONE. That portion of the product of the crusher which, when tested by means of laboratory screens, will meet the following requirements:

Passing .... in screen..............................	100%
Total passing .... in screen..............................	...% to ...%
Retained on .... in screen..............................	100%

"METHOD OF SAMPLING. Stone shall be sampled for quality and size in accordance with the method described on page ...., paragraphs ...., of these specifications.

"METHODS OF TESTING. Tests of the physical properties and sizes of the stone shall be made in accordance with the methods described or referred to on pages .... of these specifications, Tests Nos. ....."

* Tests recommended by the conference which it may be desirable to omit in some instances.

8. Quarrying, Crushing and Screening Broken Stone

In Breaking Field Stone preparatory to crushing, a sledge hammer is used, one striking face being slightly rounded and the other wedge-shaped. Large boulders are drilled with hand drills, blasted with powder or dynamite, and then broken up with sledge hammers.

In Quarrying Ledge Stone, HAND DRILLING is slow and somewhat more expensive than machine drilling. There are three well-known methods of hand drilling. For shallow holes of small diameter one man holds a small drill with one hand while he strikes it with a small hammer held by the other hand. For large holes of greater depth, one man holds a drill while two other men strike alternately with large hammers weighing 8 to 12 lb. Another method is sometimes called churn drilling, in which one or two men lift the drill a few inches and let it fall again, thus using the weight of the drill instead of the blow of a hammer to cause the impact. In all hand drilling the workmen must revolve the drill slightly between each impact in order to keep the hole circular and to prevent binding. One man with a churn drill will drill from 6 to 18 in of 2-in holes per hr. After a hole has been drilled to a depth of about 4 ft, two men are required to handle one drill. Churn drilling, if the holes are to be vertical, is the most economical form of hand drilling. In all drilling the drills have to be sharpened frequently, varying with the hardness of the stone.

Nearly all quarrying of ledge stone is now carried on with POWER DRILLS, operated by steam, gasolene or electric power. No general rule can be made for either type of power. In large plants for general sale of broken stone steam power is most generally used. A steam drilling outfit is cumbersome and heavy, consequently, when the outfit is to be moved from place to place, the air compressor, using a gasolene engine for power, is useful and desirable. Such an outfit, suitable for operating three drills, including drills, hose pipe and all necessary adjuncts, costs about $2200. In all power drills, except rotating drills which are not used in rock suitable for road making, the power is applied to the drill in such manner that there are many blows to the minute of short strokes. A blacksmith equipment is necessary with all outfits.

The Cost of Quarrying Stone, including breaking the stone to sizes that will go into a crusher, varies with the quality of the rock and with the size to which the stone must be reduced for the crusher. It may be as low as $0.30 per ton in a large, well-equipped plant where several hundred tons of stone are crushed daily, or as high as $0.60 per ton in a small plant which turns out less than 100 tons per day.

For further details pertaining to quarrying see Sect. 3, Arts. 17 to 19 inc.

Crushers are of two types. The gyratory crusher is used in large or permanent plants, and the jaw crusher in small or portable plants. The following tables show data relating to the standard types of gyratory and jaw crushers.

Power for operating crushing outfits consists usually of steam engines and boilers, altho gasolene engines are sometimes used. Permanent plants of course have stationary machinery, but plants for local use consist of boiler and engine combined and mounted on steel wheels and axles. The most commonly used portable plants consist of a 15 or 20 H.P. engine and boiler, altho infrequently large outfits up to 50 H.P. are used on large works.

Elevators and Screens. Bucket elevators are used to carry the output of the crusher to elevated revolving circular screens, the screens being so

Weights, Capacities and Power Required for Gyratory Crushers

Size	Dimensions, Receiving Spider Openings		Capacity in tons per Hr, Varying with Character of Rock		H.P. for Crusher, Elevator and Screen	Approximate Weight of Crusher
	Each About	Both About	Tons	To Pass Diameter Ring		
2......	8 by 22	8 by 44	5 to 10	2¼	12 to 15	10 000
3......	8½ by 24	8½ by 48	10 to 20	2½	20 to 25	15 500
4......	9 by 27	9 by 54	15 to 30	2½	25 to 30	23 500
5......	12 by 35½	12 by 71	25 to 50	2½	30 to 50	32 000
6......	12½ by 37	12½ by 74	45 to 90	3	40 to 60	44 000
7½...	14 by 44	14 by 88	90 to 150	3½	75 to 125	67 500
8......	19 by 60	19 by 120	130 to 225	4	100 to 150	100 000
10......	25½ by 72	25½ by 144	400 to 600	5	175 to 250	180 000

Weights, Capacities and Power Required for Jaw Crushers

Number by Which Each Size of Crusher is Known	No. 1½	No. 2	No. 2½	No. 3	No. 4
Approximate cost....	$800	$900	$1200	$1300	$2000
Size of jaw opening for receiving stone, in inches..........	8 by 15	9 by 16	10 by 20	10½ by 22	12 by 28
Product per hour in tons when machine closes to 2 in.......	10 to 15	12 to 18	15 to 25	15 to 30	25 to 40
Weight in pounds....	5000	7000	9250	15 500	27 000
Weight, mounted on 4 wheels, with 12-ft elevator, in pounds..	7500	9500	12 000	Not mounted	Not mounted
Speed revolutions per minute............	275	275	265	265	240
Driving pulleys, diameter and face, in...	30 by 8	32 by 9	36 by 11	38 by 10	44 by 12
Horse-power required	12	15	20	25	35
Floor space required, length............	5 ft 6 in	6 ft 6 in	7 ft 6 in	7 ft	8 ft 6 in
Floor space required, width............	5 ft	5 ft 1 in	5 ft 9 in	5 ft 6 in	6 ft
Extreme height of machine..........	3 ft 5½ in	4 ft 3 in	5 ft 2½ in	4 ft 7 in	5 ft 7 in
Size of elevator best suited............	No. 2	No. 2	No. 2½	No. 3	No. 3
Diameter of screen best suited in inches.	30	30	36	36	42

mounted that the broken stone will gravitate from one to the other. The screens are built in sections, each section being from 2 to 4 ft in length, and in portable plants from 24 in to 36 in in diameter. The openings are circular and of one size in each section. Under the specifications adopted by the Am. Soc. Mun. Imp., the sizes of holes are as follows. First section ⅝-in holes; second section, 1¼-in holes; third section, 2¼-in holes; fourth section, 3½-in holes. In many cases, however, the screens are in three sec-

tions, the holes being ⅝ in, 1¼ in and 2½ in, respectively. When it is desired to separate the dust from the material passing the first section, a dust jacket having ¼-in openings is fitted around a portion of the first section. Bins are so arranged that the product from each screen will go to a separate compartment.

Cost Data and Description Covering Quarry and Crushing Plants

Pacoima Quarry, Los Angeles County, Cal. (33). The rock obtained at the quarry is an andesite, a volcanic rock having the following physical properties:

"Specific gravity	2.76	French coefficient of wear	17.9
Weight per cu ft	172.00 lb	Hardness	17.9
Water absorbed per cu ft	0.83 lb	Toughness	29.0
Percent of wear	2.2	Cementing value	Excellent

"The rock was being taken from two quarry openings, one having a face of about 200 ft with a height varying from 20 to 85 ft, and the other having a face of 110 ft in length and from 20 to 50 ft in height. During the early operation of the quarry as many as three 3¼-in air drills working to a depth of 24 ft were used during the day shift. As the face increased in height the number of drills was decreased until at the date of the report, only one 3¼-in drill was necessary. The holes ranged from 20 to 24 ft in depth, about 70% of them being drilled from the quarry floor as lifters, and the remainder being drilled from the top. Moisture in the hill prevents the use of black powder. Each hole is charged with from 100 to 300 lb of 40% dynamite and from one to ten holes are fired at a time.

The following table shows the total and unit costs of operation and maintenance at the Pacoima Quarry, July to December, 1910. Total output, 144 798.15 tons.

	Total Cost	Cost per Ton Cents	Percentage of Total Cost
Salaries	$2 198.98	1.52	2.9
Stripping:			
Labor	6 722.69	4.64	9.0
Drilling and blasting:			
Labor	3 496.14	2.42	4.7
Powder, 33 195 lb; 0.229 lb per ton	4 130.35	2.85	5.5
Other materials	223.52	0.15	0.3
Loading and transporting, quarry to crusher:			
Labor	36 653.32	25.32	48.9
Materials	313.36	0.22	0.4
Handling muck:			
Labor	9 804.55	6.77	12.8
Plant operation:			
Labor	2 464.96	1.70	3.2
Materials	543.32	0.38	0.7
Loading and shipping:			
Labor	1 392.56	0.96	1.9
Maintenance:			
Labor	2 021.25	1.40	2.5
Materials	1 816.02	1.25	2.4
General:			
Labor	389.27	0.27	0.5
Sundry	322.80	0.22	0.4
Power:			
Labor	2 910.03	2.01	3.9
Totals	$75 403.12	52.08	100.0
Credits:			
Boarding house profits	4 348.97	3.00	
Net cost per ton		49.08	

"A considerable amount of waste, partly from the stripping mixed with the surface rock and partly from seams, comes down in the quarry. The rock is cleaned of muck as it is loaded with forks into cars at the working face, and the accumulated muck is removed with Fresno scrapers between shifts. The cars used in the quarry are 36-in gage end dumping quarry cars having a capacity of from 2 to 2½ tons and a total height of 30 in. They are snatched by mules to the main quarry line and there, in trains of 10 cars, drawn by a 5-ton electric locomotive a maximum distance of 400 ft over a trestle to the tipple above the crusher. They are dumped by means of a special automatic cross-over mine tipple and returned to the quarry by a gravity switchback. Ten cars can be dumped in 4 min, and only one man is required to operate the mechanism.

"The rock is fed into a No. 6 gyratory crusher by one man. From this crusher it passes thru a preliminary 8-in screen, the rejections from which are returned and crushed in a No. 4 gyratory crusher. The total product is then transported by a belt conveyor to final sizing screens over the storage bins. These screens separate the stone into 4 sizes which are stored in the bins for gravity loading into railroad cars."

Quarry and Plant at Newton, Mass. (35a). The crusher was placed near a ledge of hard, green trap rock. The stone was drilled with a Rand steam drill and broken to size to go into the crusher by sledge hammers, and taken by horses and carts to the crusher, a distance of about 500 ft, and delivered on a platform level with the top of the hopper. It was fed into the hopper by two laborers. Unit costs were as follows, wages being for a 9-hr day: Foreman, $3; operator, steam drill and boiler, $3; operator crusher, $2; blacksmith, $2.50; laborer, $1.75; two one-horse carts and drivers, $5; powder per 50-lb box, $11.34; coal per ton, $5.90; oil per gal, $0.15; waste per lb. $0.09.

	Cost per Cu Yd	Cost per Ton
Labor, steam drilling	$0.092	$0.076
Steam drilling, including coal, oil, waste, powder, repairs	0.084	0.070
Sharpening drills and tools	0.069	0.058
Breaking stone for crusher	0.279	0.231
Loading stone for crusher	0.098	0.081
Teaming stone for crusher	0.072	0.060
Feeding stone to crusher	0.053	0.044
Engineer of crusher	0.031	0.026
Coal, oil waste and repairs of crusher	0.079	0.065
Repairs	0.041	0.034
Total	$0.898	$0.745

Tompkins Cove Crushing Plant, Rockland County, N. Y. (17). "The rock is blasted from a high vertical quarry face, loaded by steam shovels to cars on a high level track, and drawn an average distance of about 800 ft to the top of the crusher house. It is dumped directly into the crusher hopper and passes vertically downward thru three successive sets of horizontal crusher rolls, which reduce it to a maximum size of about 2 in. From the lower rolls it is raised about 90 ft by a steeply inclined steel pan elevator which discharges into a hopper in the top of the preliminary screen house. This hopper discharges into a distributer that spreads the broken rock evenly over a gravity screen that removes all stone larger than 1½ in and delivers it to a belt conveyor by which it is returned to the last pair of rolls. About 90% of the product which passes thru the preliminary screen is delivered by a belt conveyor 362 ft long, inclined about 10°, to the top of the main screen house where it passes by gravity vertically thru a stationary distributing and screening apparatus which separates it into 1½-in, ¾-in and ⅜-in sizes, each of which is discharged on a separate horizontal belt conveyor and dumped into one of the five storage bins with a combined capacity of 20 000 cu yd."

CONSTRUCTION

9. Methods of Construction

Subgrade. The subgrade is usually a shallow trench composed of two or more planes or a curved surface sloping from the center to the sides. The surface of the subgrade is generally parallel to the finished surface of the broken stone road, altho this is not true when the depth of stone at the edge of the shoulder is made less than at the center (see Figs. 5 and 6.) The subgrade has the same width as the broken stone surface. The sides of the trench, which serve to hold the stone in place, are formed by earth shoulders, generally from 3 to 5 ft in width. In places where the edge of the stone is bounded by a curb or gutter, the earth shoulder is generally omitted unless the roadway is extremely wide and only a part of the width is built of broken stone. The subgrade should be brought to true line and grade and be thoroly compacted with a steam roller. Any low spots which appear during compaction should be brought up to grade with good material and rerolled.

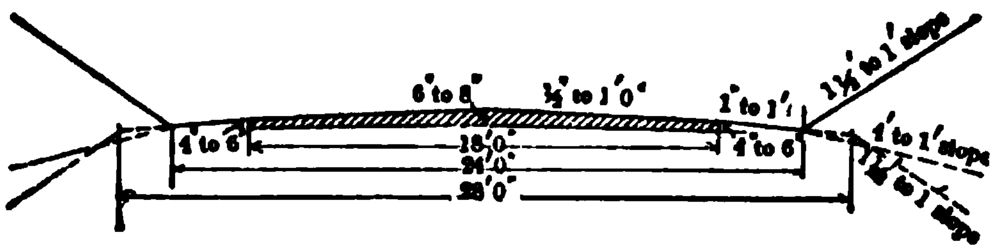

Fig. 5. Cross-Section of a Broken Stone Road on a Natural Road-Bed. Full lines show shoulders and slopes in cuts; broken lines, shoulders and slopes for embankments

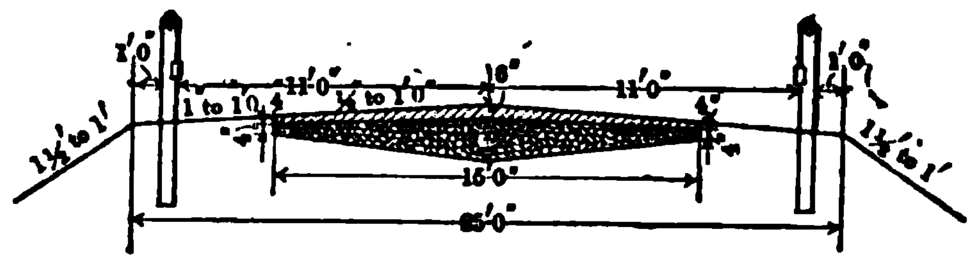

Fig. 6. Cross-Section of Broken Stone Road on a V-Drain Foundation Constructed on an Embankment

Hauling the Broken Stone. The road metal may be hauled to the highway with ordinary carts or wagons. Patent bottom dump-wagons with doors hinged on the sides or on the ends of the wagons are commonly used and serve the purpose in an excellent manner. It is possible with this type of wagon to regulate the size of opening between the bottom doors so that any width of opening up to the maximum can be obtained. By this means it is possible to spread the stone in layers as the wagon is drawn along the road. Similar wagons are built to be hauled by a traction engine. Wagons of this type generally have a capacity of 3 to 4 cu yd and are drawn in trains.

The Effect of Distance Hauled Upon the Settlement of Crushed Limestone in Wagons and Carts is given in the following table (14):

Size of Stone	Settlement After a Haul of	
	½ Mile or More in Wagons	75 Miles or More in Cars
⅛-in screenings	12.7%	......
¼-in screenings	11.8%	10.6%
2 to ¾-in	9.2%	......
3 to 2-in	8.2%	7.0%

Laying the Broken Stone. In some cases where the stone is not of a particularly good quality, better results may be obtained by placing the smaller stone in the bottom of the road and the larger sized stone on top. There are also cases where the run of the crusher from the coarse sizes down to dust is placed on the road as one course, but this method is not recommended. If the stone is brought in patent bottom dump-wagons, it may be dumped directly upon the subgrade and spread with forks. Stone brought to the work for the upper courses of a road, however, should be dumped on boards and shovelled in place to prevent the segregation of the sizes, which might occur if the stone was dumped directly upon the road from the wagons.

Thickness of Courses. All broken stone roads should be constructed in layers, each layer being rolled before a subsequent layer is placed. The thickness of any layer should not exceed 4 in after rolling, as it is impracticable to properly roll a layer of greater thickness. For roads under light traffic, assuming a good natural or artificial foundation, the total thickness of the crust, if of trap or other hard rock, need not be more than 4 in; if of softer stone, 5 to 6 in. If the traffic is heavy the thickness should be greater. A thickness of 8 to 10 in is not unusual where the traffic is of heavily loaded vehicles, that is, frequent loads of 10 tons or more. With very frequent loads of 10 tons or more, a water-bound broken stone road should not be constructed and the same is true if more than about one third of the traffic is of fast moving motor-driven vehicles. The thickness of the bottom course is varied according to the kind of foundation and the nature of the traffic to be carried. If the natural subsoil is of good firm material like good road gravel, or if the road is built upon an artificial foundation of stone, the lower course may be as thin as 2 in, provided the traffic over the roadway is of vehicles weighing not more than 4 or 5 tons. If, however, the vehicles passing over the roadway are of heavy type, the road will be sufficiently more permanent to warrant making the lower course more than 4 in in thickness. On streets of cities it is often economical to construct the lower course 6 in in thickness after rolling.

Regulating the Thickness. To gage the thickness of a layer of stone, wooden cubes made equal to the depth of a layer are sometimes placed at intervals across the roadway, the cubes being taken up and moved along as the work progresses. With this method, however, if there are any irregularities in the subgrade or in the foundation course, they will be carried up to the finished surface. A better method of regulating the depths of the different layers is to set strings longitudinally at the proper elevation at the sides and center of the roadway. In this manner the elevations are always tied in with the finished grade and any irregularities can more readily be corrected as they occur.

The Amount of Broken Stone per Unit of Area of Roadway Surface will of course vary with the thickness of the crust, but, in some cases, does not vary in exact proportions to the thickness of the crust on account of the fact that the voids in the lower courses are not always filled with stone dust. In some cases the voids are filled with dust to a depth below the top of the wearing surface of not exceeding 3 in, and often not exceeding 2 in, hence the weight per unit area of the top course is greater than the weight per unit area of the lower course or courses of the same thickness.

" Surface Covered by Various Sized Loads of Broken Stone (44). The following tabulation shows the number of linear feet of 9-ft road a load of a given size should cover for various loose depths:

Weight of Load			Loose Depth in Inches			
Granite	Limestone	Size of Load Cu Yd	3 in Ft	4 in Ft	5 in Ft	6 in Ft
2800	2500	1	12	9.00	7.2	6.0
3500	3125	1¼	15	11.25	9.0	7.5
4200	3750	1½	18	13.50	10.8	9.0
4900	4375	1¾	21	15.75	12.6	10.5
5600	5000	2	24	18.00	14.4	12.0
6300	5625	2¼	27	20.25	16.2	13.5
7000	6250	2½	30	22.50	18.0	15.0
7700	6875	2¾	33	24.75	19.8	16.5
8400	7500	3	36	27.00	21.6	18.0

Rolling. Horse-drawn rollers are not sufficiently heavy to properly roll broken stone. If the stone is a hard trap, a roller weighing from 12 to 20 tons is desirable, but if the stone is soft a roller weighing from 10 to 15 tons is better than the heavier type. Ordinarily, about 10 tons per hour is considered the amount of stone that can be properly rolled with one roller. Up to the present time steam is the only power universally successful for rollers, but gasoline engines may prove to be of use if properly designed for the variable conditions a roller is required to meet. The amount of rolling necessary depends on the character of the stone, the weight of the roller, and upon the amount of water and binder used. Trap rock requires two or three times as much rolling as most stone. The usual speed of steam rollers is 2 to 2½ miles per hr. The amount of rolling required varies from 4 to 10 tons of broken stone per hr.

Settlement in Rolling (3). In order to know the depth of loose broken stone to be spread to give a required depth after rolling, it is necessary to know the settlement due to rolling. The apparent settlement depends upon the nature of the subgrade, that is, upon the amount of stone forced into the earth. The maximum actual settlement is probably less than 20%. In the case of a subgrade so hard that wagons hauling stone made no ruts, 5¾ in of trap rock 1½ to 2¼ in in diameter, rolled with a 12-ton steam roller down to 4 in, and 7½ in rolled down to 6 in. With hard limestone 6 in loose rolled down to 4¾ in.

Applying Screenings. In some specifications it is stated that the voids in the foundation course shall be filled with stone screenings, sand, or gravel, the fine binding material to be thoroly swept in, watered, and rolled. No surplus material, however, is allowed to remain on the surface of the foundation course. This method of construction provides a firmer foundation than where the voids between the stone are not so filled. The same treatment is also frequently used to facilitate the rolling of the foundation course where the stone is of such a character that it will not readily compact under the action of the roller. Screenings are generally used in connection with the construction of the upper course. When this course has been firmly compacted, the surface is covered with a layer of stone screenings and thoroly sprinkled with water, which washes the screenings into the voids in the stone. More screenings are added as desired and rolling is continued, the surface being sprinkled in front of the roller. When the proper amount of water and screenings has been used, a wave of grout will be pushed along in front of the roller. A coating of screenings should be laid over the entire surface, no more being used than is necessary to

cover the stone. The stone screenings resulting from the crushing of the rock with which the first two courses are filled are generally used for the binder.

Amount of Binder (3). The amount of binder required depends upon the character of the stone and upon the amount of rolling it has received before the binder is spread. If the voids after rolling are about 22%, the completed road having about 5% voids, enough binder must be added to fill about 17% of voids. The binder contains about 50% voids, so about 25% of binder will be required. For example, for trap macadam 15 ft wide, average thickness 5 in, 100 ft long, the amount of binder would be calculated as follows: $15 \times 100 \times 0.42 = 630$ cu ft per 100 lin ft; as 25% of 630 = 157 cu ft voids; screenings or binder weigh approximately 2500 lb per cu yd, or 93 lb per cu ft, $157 \times 93 = 7.2$ tons of binder required.

The Illinois Highway Commission's Instructions to Its Engineers (26) covering the construction of broken stone roads are as follows:

"PLACING STONE. On all roads except very narrow ones, the placing of stone should begin on the end nearest the stone pile and be carried from it so that the stone road will be available for hauling the stone. A 12-ft water-bound macadam, 8 in thick, requires 18 cu yd per 100 ft in each course of stone. To get this quantity the wagons should be measured and the capacity chalked on the sides, if they vary. If all are of practically the same capacity, it is unnecessary to mark them. In measuring, make liberal allowance for heaping above the boards. Having determined the capacity of the wagons, figure the distance each load should cover and give the dumper a stick, cut for the distance the wagons should be spaced when dumped. The loads should be dumped in the middle of the subgrade. If the loads vary, the measuring stick should have notches properly marked for each size of wagon. The usual tendency is to use too much stone and the amount used should be checked after each spreading, to be sure that the stone does not exceed the thickness shown on the plans. As an additional check, use the car weights of the stone, and determine whether at 2500 lb per cu yd it will cover the proper amount of roadway. The quantity of stone required for a road of any other width or thickness should be checked in the same manner.

"SPREADING STONE. When a sufficient amount of stone has been dumped, it should be spread with a road machine. The following method is most satisfactory: Set the blade square across the road and use two teams, hitched tandem, on the grader. For the first three or four trips, drive in the middle with the blade held level and drag the stone lengthwise of the road, allowing it to spread what it will, scraping only the tops of the loads at first. Then set the blade to throw material towards the shoulder and make the rounds on the sides, holding the blade to conform to the crown of the road. If depressions appear as the spreading progresses, do not add additional stone, but keep dragging with the grader until the surface is uniform. Give the stone a final touching up with hand rakes.

"HARROWING. Both courses of stone are to be harrowed after they are spread, but in no case should the harrow be expected to spread the stone or remove depressions. The use of the harrow is to bring the larger stone to the surface and to shake down any small material that may be mixed with it. The harrowing is also important on the top course of poured bituminous macadam to shake the dust from the individual stones, giving a clean surface for the bitumen. Usually three or four trips over a given area are required, but where the 2½-in stone comes very dirty, on account of cinders in the bottom of the car or under the storage pile, a greater amount of harrowing may be required. Dirty stone should never be used for the top course.

"ROLLING STONE. The roller must be run at not to exceed 100 ft per min. The rolling should begin at the edge of the macadam on lower course work, and the roller should work towards the crown line about half a wheel width at a trip. When one side has been gone over, the other side should be rolled and the rolling continued alternately on each side of the macadam until the stone is thoroly compacted. On the upper course the rolling should begin on the shoulder and should be done in the same general way as for the lower course except that it should begin 5 ft out on each shoulder. The condition of the surface must be studied carefully until it is properly compacted. The condition to be attained is to have the stone keyed together so that it will not be greatly disturbed by a load going over the surface. If Chester stone is used, it is possible to roll too much, causing the stone to spall. The Joliet stone, if rolled too

long, will wear smooth from abrasion under the roller and become loose. With either stone, therefore, the rolling must be watched carefully.

"SPREADING SCREENINGS. After the second course of stone has been properly rolled, the screenings shall be spread from piles dumped alongside the road. It will require from 4 to 5 cu yd of screenings per 100 ft of 12-ft road. The screenings should be dumped half loads in a place and hauled before the top course of stone is rolled, and must be dumped far enough from the stone to permit rolling the shoulder next to the stone. The screenings should be spread with square-end shovels, being whipped into the voids from the shovels. The screenings should not be thrown on the road surface in bunches. After the screenings have been spread, the surface should be gone over with a stiff brush to distribute the screenings uniformly. After the screenings have been spread, they should be watered lightly and allowed to stand. A good plan is to arrange the work so that the screenings are spread and watered just before the close of a day's work. In the morning a second light sprinkling may be applied and the surface rolled. If the screenings are of such a nature that when wet they stick to the roller, they should be wet by driving the sprinkler on the shoulder and spraying the water on the surface from one spray nozzle. Then allow the surface to dry until the roller does not stick, and roll thoroly. Repeat the process of wetting and rolling a few days after the first finishing and keep traffic off until the screenings set. In hot, dry weather, 2 days are sufficient; in cool weather, 4 or 5 days are required. The final rolling should be done driving the sprinkling wagon immediately ahead of the roller. The surface at this time should be so compact that the water flushes to the top under the action of the roller. Care must at all times be used not to apply so much water as to soften the subgrade. If this happens, keep the roller off that portion of the road until the foundation has had time to dry. After the road has been opened for traffic, watch carefully for any signs of raveling and patch them as soon as they appear. To do so, loosen the surface stones where the break appears, add a few additional stones, roll, cover with screenings, and sprinkle. When the road is opened to traffic, it should have from ¼ to ½ in of screenings on the surface."

10. Specifications for Construction

Am. Soc. Mun. Imp. (12). For sections covering physical properties and sizes of broken stone, see Art. 7.

"GENERAL DESCRIPTION. The broken stone road shall consist of three courses of broken stone, separately constructed, laid to conform to the required grades and cross-sections and constructed as hereinafter specified.

"FIRST COURSE. After the subgrade or subbase course shall have been prepared as specified, a course of No. 4 broken stone shall be evenly spread so that it shall have after rolling the required thickness of 3½ in. The depth of loose broken stone shall be gaged by the use of strings between iron stakes, as directed. The spreading of the broken stone must be from piles dumped on boards provided for the purpose or from piles dumped alongside the road, or as directed by the Engineer. This course shall be thoroly rolled with a 10 to 15-ton road roller. The rolling shall begin at the sides of the road and continue towards the center and shall be kept up until there is no disturbance of the stone ahead of the roller. After the completion of the rolling, no teaming other than that necessary for bringing on the broken stone for the next course shall be allowed over the rolled broken stone. Should it be apparent after the rolling of the first course that the subgrade material shall have become churned up into or mixed with the broken stone of this course, whether by reason of the rolling, or by hauling over the broken stone or otherwise, the Contractor shall at his own expense remove and replace such mixture of subgrade material and broken stone with clean broken stone of the proper size and shall roll the material to produce a uniform, firm and even first course as required.

"SECOND COURSE. On the completed first course shall be spread, in the manner specified in the preceding paragraph, No. 3 broken stone to form the second course. This broken stone shall be evenly spread to such a depth that it shall have after rolling the required thickness of 2½ in. After the second course shall be compacted under the same provisions as prescribed for the first course, it shall be evenly covered with a thin layer of screenings. The quantity of screenings to be used shall be just sufficient to cover the larger stones and care shall be exercised to avoid the use of an excess

of the screenings. This covering shall then be rolled as heretofore provided. When the rolling shall have been completed the surface of the second course shall be firm, even and true to the lines, grades and cross-sections.

"THIRD COURSE. On the completed second course shall be spread in the manner above specified for the first course No. 3 broken stone to form the third course. This broken stone shall be evenly spread to such a depth that it will have after rolling the required thickness of 2½ in. After the third course shall have been compacted under the same provisions as prescribed for the first course, it shall be evenly covered with a thin layer of screenings. The quantity of screenings to be used shall be just sufficient to cover the larger stones and care shall be exercised to avoid the use of an excess of the screenings. This covering shall then be rolled as heretofore provided except that water shall be used in connection with the rolling as follows: After the screenings shall have been lightly rolled, water shall be sprinkled on the road surface just ahead of the roller in such quantity as will prevent the sticking to the wheels of the roller of the fine material on the surface, and the combined spreading of screenings, watering and rolling shall be continued until the voids of the broken stone become so filled with the finer particles as to result in a wave of grout being pushed along the road surface by the front wheel of the roller. When the rolling shall have been completed the surface of the third course shall be firm, even and true to the lines, grades and cross-sections. After the third course has been compacted, puddled and filled as above specified, it shall be evenly covered with a thin layer of screenings. Should at any time, after its construction and prior to the acceptance of the road, the larger stone be visible in the surface of the road, the Contractor shall, without extra allowance, spread, sprinkle and roll sufficient screenings to completely cover the same.

"MEASUREMENT AND PAYMENT. The quantity of broken stone road to be paid for shall be the number of square yards, measured horizontally, satisfactorily completed in accordance with the specifications. The price stipulated shall include the furnishing, crushing and screening of the different sizes of broken stone, the placing, rolling and watering of the broken stone, and all work and expenses incidental to the completion of the broken stone road.

Mass. Highway Comm. specifications, substantially as used by many states, counties and municipalities in New England, are as follows:

"Before the surfacing is spread the road-bed shall be shaped to a true surface conforming to the proposed cross-section of the highway and rolled by a steam roller. All depressions occurring must be filled with suitable material and again rolled, until the surface is smooth and hard.

"Broken stone shall be spread and rolled on the road-bed prepared as hereinbefore described, as follows:

"The width of the broken stone shall be 18 ft.

"All broken stone used shall be laid in layers or courses. The lower course shall consist of stones that will pass thru a ring of 2½ in in diameter and will not pass thru a ring 1¼ in in diameter; the upper course shall consist of stones that will pass thru a ring 1¼ in in diameter but will not pass thru a ring ½ in in diameter.

"The lower course shall be 4 in deep at the center and 3 in deep at the sides after rolling. The upper course shall be 2 in deep at the center and 2 in deep at the sides after rolling.

"After the two courses above described are thoroly compacted, broken stone screenings shall be thinly spread over the stone surface, watered and rolled until the mud flushes to the surface. As the stone screenings are watered and rolled, voids between the larger stones will appear in the surface and this operation of thinly spreading the screenings, watering and rolling, and flushing out, shall be continued until the surface is completed to the satisfaction of the Engineer. Screenings so used shall not be larger than will pass thru a ½-in mesh sieve. Whenever the Engineer may direct, roads shall be allowed to dry out between periods of watering and rolling.

"Each course shall be rolled separately by a steam roller and evened up with material of the same size and quality as has been used in that particular course, and to the satisfaction of the Engineer.

"All broken stone shall be spread from carts by hand, or from a dumping board, or from self-spreading carts which shall be of a type approved by the Engineer. No soft or disintegrated stone shall be used.

"If so ordered by the Engineer the thickness of the broken stone shall be increased or diminished at such points as he may direct.

"The finished surface of the road shall present such crown as shall be directed by the Engineer."

New York Commission of Highways. "The sizes of all stone used under these specifications shall be determined by the size of screen aperture thru which the stone will pass when revolved in a rotary screen. They shall be designated as follows:

Diameter of Aperture Min.	Max.	
	¼-in square	Screenings
¼-in square	⅝-in circular	No. 1
⅝-in circular	1¼-in circular	No. 2
1¼-in circular	2¼-in circular	No. 3
2¼-in circular	3½-in circular	No. 4

"Broken stone shall be clean and sharp angled, shall pass the standard tests for abrasion and toughness as adopted by the Am. Soc. Test. Mat., and shall be approved by the Bureau of Tests and acceptable to the engineer before being used.

"Field stones, boulders or fence stones which are crushed for macadam purposes shall be 6 or more inches in diameter, if consisting of rounded cobbles. If of the flat variety, the minimum thickness shall be 2 in, which latter requirement will also apply to laminated quarry stone.

"If after trial it is found that partially developed quarries, ledges or other sources of supply do not furnish a uniform product, or if, for any reason, the product from any source, at any time, proves to be unsatisfactory to the engineer, said engineer may require the contractor to furnish stone from other sources of supply, and the contractor shall have no claim for increased payment on account of such requirement.

"The contractor shall furnish one or more stone crushing plants of type, composition, and capacity satisfactory to the engineer. The rotary screens shall be provided with openings of size and shape given under Stone Sizes, unless otherwise ordered by the engineer.

"All crushing plants installed on the work shall be fitted up with a tailing chute so that no stone will reach the bins other than that which passes thru the proper screen.

"All stone must be of the required size when placed in the roadway, and no breaking up of stone by hammers or otherwise will be permitted after the stone has been placed in the work.

"In no case shall any constituent of macadam pavement be dumped into place in mass; the final placing shall be by shovel or by thin spreading such that no appreciable fall occurs.

"The spreading of any layer or course of broken stone, gravel or filler, whether in foundation, bottom or top courses, shall be done from suitable spreader wagons or from piles dumped along the road as directed by the Engineer.

"No segregation of large or fine particles will be allowed, but the stone as spread shall be well graded with no pockets of fine material.

"The quantity to be paid for under this item shall be the number of cubic yards of compacted material in place in the completed course. The amount to be estimated shall be computed by multiplying the finished cross-section of the bottom course as shown on the plans or ordered by the Engineer, by the length of the bottom course measured along the axis of the pavement.

"After the subgrade or foundation course shall have been properly prepared and proper drainage provided, a course of broken stone or graded No. 3 or No. 4 size or a uniform mixture of same shall be spread evenly so that it will have after rolling the required thickness. If specifically allowed by the Engineer a limited amount of No. 2 stone may be used in the bottom course.

"In cases where the finished thickness of the bottom course is to be more than 5 in, the broken stone or gravel for it shall be spread, rolled and filled in two separate layers neither of which shall be of a greater depth than 6 in measured loose.

"The depth of loose stone in all cases, whether in foundation, bottom or top courses, shall be gaged by the use of cubical blocks of suitable size.

"After the bottom course of stone has been laid loose it shall be thoroly rolled with an approved roller weighing not less than 10 tons.

"This rolling must begin at the sides and continue toward the center and shall continue until there is no disturbance of the stone ahead of the roller. After the stone is thoroly compacted, No. 1 stone or gravel, and screenings or sand, or a mixture of these, shall be uniformly spread upon the surface and swept in with the rattan or steel brooms and rolled dry. After the completion of the rolling no teaming other than that necessary for bringing material for the next course shall be allowed over the rolled material. It is the intention to bind this course with the small stone, but not to use so much that a good bond will not be secured between the bottom and top courses.

"When two courses of bottom stone are laid each course shall be treated by rolling and adding fine material as described above.

"If the subgrade material shall become churned up into or mixed with the bottom or subbottom courses thru the Contractor's hauling over it or working on it when the subgrade is in a wet condition, the Contractor shall at his own expense remove such mixture of subgrade material and broken stone and replace it with clean broken stone of the proper size, and shall roll or otherwise compact the material so as to produce a uniform, firm and even bottom course.

"If the above condition occurs thru no fault of the Contractor, the Contractor shall be paid both for excavating and replacing under the items Excavation and Bottom Course respectively.

"All filler for top and bottom courses shall be delivered and piled alongside the road before the course in which it is to be used is placed.

"The top course shall, except as noted below, consist of No. 3 broken stone as shown on the plans and of the thickness shown thereon, together with the binder necessary to properly fill and bind the course. The binder shall consist of screenings and No. 1 stone mixed.

"The No. 3 stone shall be spread evenly upon the bottom course, using cubical blocks for gaging, to such a depth as to insure the required thickness after it shall have been thoroly rolled and compacted. Care shall be used in the spreading of the stone that no irregularities in the contour shall develop in the rolling; every such irregularity that does occur the Contractor shall remove before adding the smaller material. The rolling shall be done with a 10 to 12 ton self-propelled roller of approved pattern, and shall be continued until the layer of stone does not creep or wave ahead of the roller.

"After the stone has been compacted to the satisfaction of the Engineer, a light coating of binder shall be spread on dry by shovelling from piles previously placed alongside the pavement, and immediately swept in and thoroly rolled. Care must be taken thruout to add the binder only in light coatings and to thoroly sweep each coating in order that the maximum amount of binder may be worked in to fill the voids. The spreading and sweeping and rolling shall be continued until no more binder will go in dry, after which the macadam shall be sprinkled until saturated, the sprinkler being followed by the roller. If the subgrade should become wet to such an extent that the pavement becomes unstable and waves under the roller, the roller shall be taken off and this portion left to dry out before puddling is resumed.

"More screenings shall be added where necessary, and the sweeping, sprinkling, and rolling shall continue until a grout has been formed that shall fill all the voids and be pushed into a wave by the wheels of the roller. After the wave of grout has been produced over the whole section of the macadam this portion shall be left to dry out, after which it shall be opened to traffic. The macadam shall be repuddled and back-rolled on succeeding days as much as may be necessary to secure satisfactory results. The macadam shall then be covered with a wearing carpet of screenings at least ⅜ in thick; this wearing carpet shall be maintained and renewed until the whole road is accepted. During all the working hours when the roller is not needed for rolling the fills, subgrade, shoulders, and unfinished courses of the pavement, it shall be employed in back-rolling the earlier portions of the macadam."

Tennessee Method (36), used on an 8-mile section of the Memphis-Bristol Highway in Tennessee, consisted in separating the screenings into two sizes, one size being from ½ to ¼ in and the other the dust of fracture, and putting these two sizes on the road in separate operations. The adoption of the following specifications for building a water-bound broken stone road, both as to the method of proportioning the rock and as to sprinkling, is advocated.

1. The subgrade shall be thoroly rolled until it is firm and compact, with the proper crown of ¾ in per ft.

2. On this shall be placed 6 in of No. 1 grade rock, ranging in size from 1½ to 3 in. This shall be spread uniformly and rolled dry until the rock does not creep before the roller, or creeps just enough to set it in place without crushing.

3. Then 2 in of stone of No. 2 grade, ranging in size from ½ to 1½ in, shall be spread uniformly, sprinkled, and rolled thoroly into the voids of the No. 1 grade.

4. Then ¾ in of the coarse material from the screenings, consisting of sizes from ¼ to ½ in, shall be spread uniformly, sprinkled, and rolled thoroly into the voids of the No. 2 grade.

5. Finally, ¼ in of the dust from the screenings shall be spread, preferably by hand from shovels, thoroly soaked, and rolled to a finish.

"This method gave a surface which is virtually impervious to water and was less affected by automobile traffic than the ordinary type of broken stone road. From the contractor's point of view it was found practicable to care for 100 cu yd of broken stone per day with one 10-ton roller, while with other types of broken stone roads it was found difficult to properly roll one-half this quantity and secure the proper bond."

Road Board of England. "These general directions are intended for use in cases where a new surface coating is to be laid with steam rolled water-bound macadam on any road which has a proper foundation or subcrust of adequate thickness.

"Trial Trenches. Before laying the new surface the thickness of the old crust including the foundation should be ascertained by opening trial trenches at intervals averaging about 150 yd apart, extending from the side to the center of the road, such trenches to be made alternately on opposite sides of the road. A careful record of the facts disclosed by these trenches should be kept with plans and sections for future reference.

"If a proper foundation or subcrust of adequate thickness does not exist, or if the road is weak at the haunches, the following steps should be taken.

"In the case of heavily trafficked roads the haunches should be strengthened and the crust thickened either with stone of any kind suitable for bottoming work, broken to a gage of from 3 to 4 in, or with hard core, clinkers or other suitable materials, according to the nature of the subsoil. In some cases, where the surface of the broken stone after being steam rolled is sufficiently smooth for the purpose of traffic, it may be possible to allow the bottoming material to be used as the wearing surface of the road for a short period, not exceeding 12 months, if it is important for financial reasons to postpone for that period the laying down of the final surface coating in accordance with the other provisions contained in these general directions.

"Total Thickness of Crust. Even when there exists a good natural foundation, the total thickness of the road crust, including the old and the new macadam after consolidation by rolling, should not be less than 4 in. In the case of well drained subsoil, which cannot be materially softened by the infiltration of surface water, the total thickness, including the new consolidated surface coating as well as the subcrust and foundations, if any, should not under ordinary circumstances be less than 5 in. In the case of fairly hard clay or other yielding subsoils, the total thickness, including foundations, should not be less than 9 in. In the case of soft wet clay or bog or marshy subsoil, foundations of a special character may be required.

"Thickness of New Surface Coating. The thickness of the new surface coating of macadam when consolidated by rolling should be from 2 to 3 in, according to the traffic requirements. If it is desired that the new coating should have a greater thickness than 3 in when consolidated, the stone should be applied in two coatings separately rolled.

"Cross-Fall. The finished surface should have a cross-fall of 1 in 24, or ½ in to the ft. If the old crust is not sufficiently thick at the crown to enable this cross-fall to be obtained when a new coating of the thickness above mentioned is superadded, the old surface should be left intact and unscarified, and the thickness of the new coating of macadam should be increased as far as may be necessary. If the crust is of ample thickness, but the cross-fall excessive, it should be reduced by scarifying the surface and removing material from the crown to the sides previous to the application of the new coating. The material so loosened by scarifying should be screened, and all material finer than ½ in should be put on one side to be used for top dressing during rolling operations.

"STONE AND SCREENINGS. The road stone for the new surface coating should be stone of approved quality, broken as cubically as possible, and should contain about 70% of stone which will pass thru a 2½-in ring, but which will not pass thru a 1¾-in ring; about 20% which will pass thru a 1¾-in ring, but which will not pass thru a screen with rods ¾-in apart. The screenings forming the residue from the above, which will be obtained by the use of the ¾-in rod screen, should be kept separate and used as a top dressing during rolling operations.

"SPREADING. The stone must be spread by careful men selected for their knowledge and experience of such work, as the durability and evenness of wear of the surface obtained by steam rolled coatings greatly depend on judicious uniform spreading. The whole of the stone should be turned over in the process of spreading. Care must be taken not to allow the stone to be tipped upon the road close to the point of spreading, as this prevents a thoro turning over of the material in the act of spreading. When stones are transported by rail or by road over long distances, the different sizes of stone are liable to separate themselves, and it is important that during the act of spreading they should be well mixed so as to obviate the possibility of having larger stones on some parts of the road and smaller stones on other parts.

"Note. One ton to cover 8 to 9 sq yd may be taken as an average quantity required to give a consolidated thickness of 3 in.

"When stones are spread in thick coatings so that 1 ton covers less than 8 yd, there is a greater liability to unequal consolidation, inasmuch as stones are pushed in front of the roller until the roller surmounts them and thus a corrugated or wavy surface is formed.

"ROLLING. The rolling should be carried out by a roller of a weight of about 10 tons. This must be in charge of a skilled driver who has been specially trained for the purpose. The macadam should be consolidated by starting the work at the sides and gradually working towards the center. No water or binding should be applied until dry rolling has been carried out to a sufficient extent to form a smooth, hard surface with the correct cross-fall, with the stones well knit together and showing their faces on the surface. The cross-section of the newly rolled surface should be frequently checked by the use of a long straight-edge and level to insure that the cross-fall of 1 in 24 is correctly obtained. No spreading or rolling is to be carried out in frosty weather. When the road can not be entirely closed to traffic care should be taken to minimize inconvenience to the traveling public during the progress of the work by coating one-half the width at one time. No unrolled stone should be left on the road over night. Care should be taken not to leave a vertical or steep edge of the new coating, but the edge should be thinned out so as to afford an easy passage from the new coating to the old surface. Notice boards warning the public that steam rolling work is in progress should be placed at reasonable distances from each end of the work.

"BINDING. The binding material should be the best reasonably obtainable. It should be either of the same material as the new coating, or of granite, limestone, or slag chippings, or failing these suitable pit gravel, and the largest stone in it should not exceed ¾ in in its greatest dimension. The binding material is not to be applied until the stones have been tightly rolled as above described. It should then be spread, watered and swept over the surface during the final rolling operations, working it from the channels towards the center so as to fill the interstices or voids between the rolled stones. Care should be taken not to use more binding material or water than is absolutely necessary to insure proper consolidation. The success of water-bound steam rolling so greatly depends on the quality and quantity of the binding material used that extreme care should be taken in its selection and application.

"REROLLING. In some cases it is advisable that a steam rolled water-bound macadam surface should be lightly watered and rerolled from a week to a fortnight after the first rolling.

"RECORDS. A careful daily record should be kept of all particulars of the work, the number of men employed, the time occupied, the quantity of material used, the area of new coating finished, and also of the state of the weather and other details."

11. Construction Cost Data

Costs of broken stone roads are dependent upon availability of material and costs of labor. Local field stone is sometimes available, with short

hauls to a crusher located where both water and coal are conveniently near, all near the road to be constructed. In such a case the cost of the stone rolled in place on the road may be as low as $1.25 per ton, or about $3800 per mile of road 15 ft wide and 6 in thick. If, on the other hand, the stone has to be shipped a long distance by rail and then hauled a considerable distance by team or truck, the cost of the stone rolled in place on the road may exceed $3 per ton, or about $10 000 per mile.

Following is a list of items and costs making up the total cost of a broken stone road where the stone is imported to the work, the average haul from railroad being 2 miles, with labor at $0.22 per hr, and double team and driver, $0.60 per hr:

Crushed stone at plant	$0.60 per ton
Freight	0.55 per ton
Unloading from cars	0.07 per ton
Hauling	0.45 per ton
Spreading	0.05 per ton
Watering	0.07 per ton
Rolling	0.12 per ton
Total	$1.91 per ton

To the above costs must be added all overhead costs, including office forces and insurance, and if estimating for bidding, the profits must be added.

Using local field stone and a portable crusher the above list would be the same except that in place of the first three items there should be substituted the following:

Cost of stone at crusher	$0.50 per ton
Cost of crushing	0.25 per ton

Table VI.—Cost of Hauling Stone on Good Roads (22)

Road Number	Price per Hour of Teams	Length of Haul Miles	Cost per Ton Mile	Cost per Yard Mile
1	$0.50	1.8	$0.200	$0.240
1	0.50	1.2	0.240	0.288
2	0.62	2.0	0.200	0.240
2	0.62	1.7	0.215	0.260
2	0.62	1.1	0.230	0.275
2	0.62	0.6	0.250	0.300
2	0.62	0.2	0.500	0.600
3	0.62	3.0	0.170	0.205
3	0.62	2.75	0.175	0.210
3	0.62	2.5	0.175	0.210
3	0.62	2.0	0.190	0.230
3	0.62	1.75	0.215	0.260
3	0.62	1.5	0.230	0.280

Cost of Hauling Broken Stone by Motor Trucks (31) over macadam roads in New Jersey. "On the Jobstown Pike near Mount Holly, N. J., four 2-ton Autocar trucks, from Sept. 29 to Nov. 29, 1916, inc, hauled 3209 tons of 2½-in broken stone, 1714 tons of 1½-in and 250 tons of screenings, making a total of 5274 tons. During that time repairs and overhead charges amounted to $506.03, operating expenses were $373.87

and fuel $460, making a total cost of $1339.90. This sum divided by the total tons gives a unit hauling cost of $0.254 per ton of stone. The average round-trip haul was 5 miles. This reduces to a cost of $0.0508 per ton-mile. It is noticed that repairs plus overhead form the largest item, and these were the expenses that required vigilance.

"On this road contract, which included the rebuilding of a gravel road with 18-ft macadam, it was necessary to use teams for hauling gravel for binder and shoulders. These teams hauled 2 tons to a load and made 20 miles per day. Five dollars a day was paid for a team; therefore, it cost $0.125 per ton-mile to haul that material. This seems to afford a fair comparison with the above figures, as the trucks and teams were in use on the same work at the same time and under the same supervision."

Table VII.—Computation of Broken Stone Costs (8)

Weight, Lb per Cu Yd	Cost per ton	Cost per Cu Yd	One Cu Yd Will Lay Number of Sq Yd of the Thickness (Loose) Indicated, and at the Cost per Sq Yd Stated									
			2 In Deep		3 In Deep		4 In Deep		5 In Deep		6 In Deep	
			Number of Sq Yd	Cost per Sq Yd	Number of Sq Yd	Cost per Sq Yd	Number of Sq Yd	Cost per Sq Yd	Number of Sq Yd	Cost per Sq Yd	Number of Sq Yd	Cost per Sq Yd
2800	$3 [illegible]	$4.20	18	$.233	12	$.350	9	$.467	7.2	$.583	6	$.700
2800	2.75	3.85	18	.214	12	.321	9	.428	7.2	.535	6	.642
2800	2.50	[illegible]	18	.194	12	.292	9	.389	7.2	.486	6	.583
2800	2.25	3.15	18	.175	12	.263	9	.350	7.2	.438	6	[illegible]
2800	2.00	2.80	18	.156	12	.233	9	.311	7.2	.389	6	.467
2800	1.75	2.45	18	[illegible]	12	.204	9	.272	7.2	.340	6	.408
2800	1.50	2.10	18	.117	12	.175	9	.233	7.2	.292	6	.350
2800	1.25	1.75	18	.097	12	.146	9	.194	7.2	.243	6	.292
2800	1.00	1.40	18	.078	12	.117	9	.156	7.2	.194	[illegible]	.233
2800	0.75	1.05	18	.058	12	.088	9	.117	7.2	.146	6	.175
2800	0.50	0.70	18	.039	12	.058	9	.078	7.2	.097	6	.117
2600	3.00	3.90	18	.217	12	.325	9	.433	7.2	.542	6	[illegible]
2600	2.75	3.58	18	.199	12	.298	9	.398	7.2	.497	6	.597
2600	2.50	3.25	18	.181	12	.271	9	.361	7.2	.451	6	.542
2600	2.25	2.93	18	.163	12	.244	9	.326	7.2	.407	6	.488
2600	2.00	2.60	18	.144	12	.217	9	.289	7.2	.361	6	.433
2600	1.75	2.28	18	.127	12	.190	9	.253	7.2	.317	6	.380
2600	1.50	1.95	18	.108	12	.163	9	.217	7.2	.271	6	.325
2600	1.25	1.63	18	[illegible]	12	.136	9	.181	7.2	.226	6	[illegible]
2600	1.00	1.30	18	.072	12	.108	9	[illegible]	7.2	.181	6	.217
2600	0.75	0.98	18	.054	12	.082	9	.109	7.2	.136	6	.163
2600	0.50	0.65	18	.036	12	.054	9	.072	7.2	.090	6	.108
2400	3.00	[illegible]	18	[illegible]	12	.300	9	.400	7.2	.500	6	[illegible]
2400	2.75	3.30	18	.183	12	.275	9	.367	7.2	.458	6	.550
2400	2.50	3.00	18	.167	12	.250	9	.333	7.2	.417	6	.500
2400	2.25	2.70	18	.150	12	.225	9	.300	7.2	.375	6	.450
2400	2.00	2.40	18	.133	12	.200	9	.267	7.2	.333	6	.400
2400	1.75	2.10	18	.117	12	.175	[illegible]	.233	7.2	.292	6	.350
2400	1.50	1.80	18	.100	12	.150	9	.200	7.2	.250	6	.300
2400	1.25	1.50	18	.083	12	.125	9	.167	7.2	.208	6	.250
2400	1.00	1.20	18	.067	12	.100	9	.133	7.2	.167	6	.200
2400	0.75	0.90	18	.050	[illegible]	.075	9	.100	7.2	.125	6	.150
2400	0.50	0.60	18	.033	12	.050	9	.067	7.2	.083	6	.100

Payment for Broken Stone Roads by the Cubic Yard. The usual practice is to pay for the actual cubical contents of the road crust as measured in place after rolling. In estimating cubic yards per mile of surface, multiply the width in feet by the average thickness in inches of the section, and then multiply this product by 16.2963; for example, a crust 1 mile long, 15 ft wide and 6 in thick, contains $15 \times 6 \times 16.2963 = 1466.67$ cu yd per mile. Similarly, to ascertain quantity per 1000 ft, a constant of 3.0864 is used; or, for same width and thickness as above, $15 \times 6 \times 3.0864 = 277.78$ cu yd per 1000 ft. The actual amount of stone used is often greater than the amount paid for in contracts, due to the settlement of stone into the subgrade during process of rolling, hence a contractor, if doing work by the cubic yard in place, should take this fact under consideration when preparing his estimate for bid. Before bidding a contractor should also note carefully the details in the specifications relative to use of binder or dust. Some specifications require the voids in the lower course to be filled with dust, thereby increasing the actual quantity of stone and dust in a cubic yard of finished road. Others call for a ½-in wearing surface of dust, which does not theoretically, but does practically increase the quantity of material per square yard or cubic yard, as it frequently disappears before the contract is finished and has to be replaced before acceptance. The quantity of water required for flushing varies, but will average about 10 gal to the ton of stone.

Payment for Broken Stone Roads by the Ton requires that scales be provided, as cubical contents cannot be accurately converted to tonnage basis. For purpose of approximate estimate it may be assumed that 1 sq yd rolled in place, 1 in thick, weighs 0.055 tons if of trap or other stone of high specific gravity, or 0.05 tons if of granite, limestone or other stone of medium specific gravity. This weight does not include the dust or binder, hence, in order to determine the approximate weight of stone in a road of given thickness, the weight of the binding dust must be added, which is approximately 0.048 tons per sq yd if of trap, and 0.042 tons per sq yd if of granite, regardless of the total thickness of the crust. From this may be obtained the following formulas, assuming t represents average thickness, and w, weight of section:

Tons per mile $= [(32.2667 \times t) + 28\ ]\, w$ for trap rock;
Tons per mile $= [(29.3333 \times t) + 24.5]\, w$ for granite and limestone;
Tons per 1000 ft $= [(6.1111 \times t) + 5.33]\, w$ for trap rock;
Tons per 1000 ft $= [(5.5556 \times t) + 4.66]\, w$ for granite and limestone.

For example, a crust one mile long, 15 ft wide and 6 in thick contains $[(32.2667 \times 6) + 28]\ 15 = 3324$ tons of trap rock, of which 15 by 28 tons or 420 tons is dust binder and 2904 tons is broken stone.

Payment to contractors by the cubic yard of stone as measured after rolling in place is preferred by some engineers, while payment by the ton is preferred by others. Those preferring to pay on a per ton basis claim that it is impossible to measure accurately the volume of stone; that a variation of ¼ in in depth makes an error of 8.33% in the determination of the volume, or from $300 to $400 per mile of 18 ft roadway.

Average Prices per Square Yard of Broken Stone Roads in various localities in the United States are given in Table VIII.

Methods and Cost of Resurfacing a Broken Stone Road with Rocmac Macadam (28). "The rocmac wearing surface was constructed in the following manner: Upon the rolled stone base of the old macadam road was deposited a layer of rocmac matrix about 1¼ in in thickness. Rocmac matrix consisted merely of a mortar made of limestone screenings mixed with rocmac solution. Rocmac solution is a liquid

Table VIII

From *Municipal Engineering*, June, 1915

City	Square Yards	Price per Square Yard	Total Thickness, Inches
Springfield, Mass	6 523	$0.57	6
Providence, R. I	69 600	0.68	6
New Britain, Conn	32 500	0.68	7
Auburn, N. Y	36 000	0.70	5
Plainfield, N. J	17 900	0.57	6
Lansdowne, Pa	15 000	0.80	6
Greenville, O	5 085	0.60	8
Milwaukee, Wis	3 022	1.05	8½
Kent, Wash	38 573	0.85	6
Charlotte, N. C	17 000	0.50	6
Dade City, Fla	140 000	1.40	4
Longview, Tex	7 790	0.94	9

silicate of soda, which reacts with carbonate of lime contained in the limestone screenings and assumes a set similar to that of Portland cement altho differing markedly from Portland cement in that chemical action is not completed immediately but is recommenced with each addition of moisture after the road is completed. This fact tends to prevent the wearing of holes since abraded parts of the surface heal over after a rain. The rocmac matrix, or mortar, was covered with 4 in of coarse crushed stone and rolled. This rolling forced the stone down into the matrix, filling the voids in the stone. As the matrix rose to the surface it was broomed forward and diagonally across the road and rolling continued until a smooth even surface was secured. The road surface was then sprinkled with dry limestone screenings. Table IX gives the detailed cost of this work. The resurfacing was accomplished by day labor.

Table IX.—Cost of Resurfacing Old Macadam with Rocmac Macadam in Queen Victoria Park, Canada

	Total	Per Sq Yd Cents
Labor		
Removing old surface, 96 cu yd	$97.20	11.26
Hauling 144 cu yd of stone and screenings from Victoria Park station	119.08	12.80
Rolling	28.00	3.25
Resurfacing	63.16	7.31
Foreman	60.20	6.97
Totals	$367.64	42.59
Material		
2-in stone, 114 cu yd, 136.8 tons at $1.25	$171.00	19.82
Screenings, 30 cu yd, 36 tons at $1	36.00	4.17
Rocmac solution, 374 gal at $0.45	168.30	19.50
Totals	$375.30	43.49
Summary		
Labor	$367.64	42.59
Material	375.30	43.49
	$742.94	86.08

12. Slag and Shell Roads

Slag roads and shell roads have been used to a limited extent thruout the United States. As the details of construction are similar to those employed in the construction of broken stone roads, certain features, peculiar to each, are described in this section.

Slag Roads. Blast furnace slags are produced in the manufacture of iron and steel and, in some cases, are very similar in appearance to close-grained igneous rocks. In reducing iron ores, the impurities rise to the surface, as the iron melts in the furnace, and unite with the fluxing material. This material is drawn off in a molten condition and is cooled either in water or in the air. Sometimes it is turned out onto the ground in a semi-molten condition and forms large banks of slag. In some cases, blast furnace slag may be excavated from slag banks by means of a steam-shovel, which serves to sufficiently break up the material so that it may be screened. In converting the iron from the blast furnaces into steel by the open-hearth process, more flux is used in the process, which rises to the surface of the molten mass as slag. The slag from the open-hearth process is generally run into molds It has, in some cases, been broken up in a rock crusher into sizes suitable for road work.

Slag is used for foundation courses and in some instances to form the entire road crust. The methods used are similar to those described for the construction of broken stone roads. Slag composes the mineral aggregate of the Tarmac pavements, which are built extensively in the County of Notts and elsewhere in England (see Sect. 16).

Shell Roads. The State of Maryland has built many miles of oyster shell roads along the eastern shore of Chesapeake Bay. The shells are about the only available material for surfacing roads in that locality. Where the shells are simply thrown onto the old roadbed without previously shaping the latter, the results obtained are not very satisfactory. The shells soon push down and the mud works up, producing conditions which are not much better than before the road was improved. If the traffic follows in the same track on a shell road, ruts will be quickly formed and a horse path will be made in the center. If these low places are immediately filled with new shells, it will tend to make the traffic distribute itself over the surface and prevent, to a great extent, subsequent tracking. Shell roads, unless watered or treated with some form of dust palliative or bituminous surface, are liable to be very dusty.

Maryland State Roads Commission Specifications stipulate that the subgrade shall be firm and well rolled. The depth of the first course of shells is either 5 in or 5 in at the center and 3 in at the sides. The depth of the second course is either 3 in or 5 in at the center and 3 in at the sides. The shells are spread upon the roadbed with shovels from piles along the road or from a dumping board. They are rolled with an 8-ton roller and are sprinkled with water or bound with sand during the process of rolling until the surface is firmly compacted. The third course is composed of clean, sharp sand, spread just thick enough to cover the second course after the latter has been thoroly compacted. Shell roads cost from 40 to 50 cents per sq yd.

MAINTENANCE

13. Causes of Wear

The length of time a broken stone road will last under traffic depends principally upon the amount and nature of the traffic. If traffic is light, a broken stone surface may last 15 years if originally built of good stone on a good foundation.

Water, if allowed to stand on a broken stone surface, will soften the latter and cause it to rapidly wear out. When the frost is coming out of the ground in the spring, the surface will also be in a soft condition and require attention. The effect of horse-drawn vehicle traffic is frequently observed in the formation of the horse path, so-called, in the center of the road. If the surface is given a flat crown, this will be prevented to some extent since the traffic will be encouraged to use the entire width of surface. If the teams track each other the wheels will form ruts, particularly when the road is in a soft condition. The grinding action of the wheels wears the stone and forms dust which, in a dry state, is swept away by the wind, thus leaving the stones in the top course exposed, in which condition they are liable to be displaced by the action of traffic. A heavy traffic of motor-cars travelling at high speed will also cause the broken stone surface to ravel very quickly when the mosaic of the upper course is exposed. Sometimes when the road is in this condition and the weather has been dry, a concentrated motor traffic of only one or two days' duration will cause ravelling.

"Interstitial Wear (13). It therefore appears that a load cannot be applied at any place on the macadam surface without producing a cone of some sort below it in which the macadam is further compressed; also, if the load is sufficient to cause any sinking whatever of the surface, a crack will be formed between the cone and the unloaded parts of the mass. As the load moves this crack and all the commotion below move along with it, and the whole mass, from the top to very near the bottom, is set in motion in its turn. In this movement the stones, big and little, are forced into new positions. Not one of them moves until it is pushed, and if it is not forced into a cavity already formed, it is forced against something else which opposes the movement. If this obstacle does not yield the pressure may be great enough to break it. It is easier to displace or to crush a small stone than a large one, and the smaller it is the more easily it is dealt with. The net result of the movement under the passing load is that the whole mass is being ground up into smaller fragments; the larger pieces get their corners and edges broken off, and the angular, flat-sided pieces of the original mass become like rounded pebbles. The moving load makes these bigger pieces act like the pebbles in a cement grinding mill; the smaller pieces are broken down to sand, and the sand is ground down to mud, or to dust, according to circumstances."

14. Methods of Maintenance

Maintenance of a broken stone road should begin as soon as the construction ceases. Ordinary repairs should be accomplished under what is called the continuous system of maintenance, that is, a system where the roads are constantly looked after and any necessary repairs are immediately made. Not only is the continuous system of maintenance the cheapest in the end, but it also keeps the road in a good state of repair. The patrol system of maintenance as carried out in France is a good illustration of what can be accomplished by this method.

Ordinary Repairs. To provide against failure from any of the causes enumerated in Art. 13, the following essential principles of maintenance work are given. At all times the surface of the road should be kept smooth. This enables the road to shed water more readily and eliminates shocks which would result from the traffic where the surface is uneven. Any hollows or pot-holes, which develop in the surface, should be repaired as soon as formed. Particular attention should be given to eliminating the ruts, since any depressions in the surface hold water, and are enlarged very rapidly by the action of traffic. Broken stone of the same size as is used in the upper course should be used in filling in the depressions and ruts. In France and England, it has been found that, in repairing pot-holes, the best

results are obtained if the holes are cut out on the lines of a square or rectangle which is of sufficient area to include the depression, the sides to be cut thru for the full depth of the wearing course. The stone is replaced, carefully tamped, filled with screenings, and puddled, or it is incorporated with some bituminous material either before or after placing. Rolling in the spring of the year, when the road is soft, will be of great help in providing a smooth surface for the remainder of the season. An excess of dust or mud on the surface should be removed, since dust is not only very objectionable from the standpoint of comfort to the traffic, but when wet it forms mud, which keeps the surface of the road in a moist condition, sometimes for a long period. On the other hand, when the upper course of stone presents a mosaic surface, sand, stone screenings, or other binding material should be spread on the surface to prevent ravelling. The surface is best preserved, however, by applying, to the swept surface of the road, a film of asphaltic oil or tar, which acts as a binder and dust layer.

The earth shoulder between the stone surfacing and the ditch should be trimmed up from time to time, so that water flowing from the surface of the road will not be impeded in its progress to the ditch. This work can, in many cases, be done in a satisfactory and economic manner by the use of a road scraper. The material removed from the shoulders, however, should never be thrown up into the center of the stone surface. As is the case in earth and gravel roads, the ditches and drains should be carefully looked after to provide for the ready flow of water.

Resurfacing. It is customary to resurface a broken stone road as soon as the top layer of stone is worn thru. The method of resurfacing depends upon the thickness of the layer of stone to be added. If 2 in or less in thickness of stone is to be added, the surface of the old road should be lightly scarified or loosened, in order to get a suitable bond between the old surface and the new; stone should then be spread and rolled in the same manner as in the laying of the upper surface in new construction (see Art. 9). If 3 in of stone is to be added it is not necessary to disturb the old surface before adding the new.

15. Maintenance Cost Data

The cost of maintenance varies with the quality and cost of materials, cost of labor, climate, amount and character of the traffic and the condition in which the road is maintained.

The cost of maintaining a broken stone road per square yard per annum in several localities is as follows:

London. Heavy traffic streets, \$0.6250; moderate traffic streets, \$0.2975; light traffic streets, \$0.1450; lightest traffic streets, \$0.0625.

In the Department of Havre, France, for departmental roads in cities, it is \$0.03, and in the country, \$0.018 per sq yd per annum.

Massachusetts state roads before the advent of the automobile was about \$0.01 per sq yd per annum.

It is evident that a more durable type of road should have been constructed where the maintenance costs are as high as that given above for the streets of London. Water-bound broken stone roads with a light traffic can be economically maintained with an application of light oil or tar applied cold at the rate of about $^3/_5$ of a gal per sq yd, at a cost of about \$0.03 per sq yd per year.

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SECTION 12

BITUMINOUS MATERIALS

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HYDROCARBONS

1. Composition and Classification of Hydrocarbons

Bitumen. The bitumen of bituminous materials used in highway engineering consists mainly of hydrocarbons and almost invariably lesser amounts of their sulphur, oxygen, and nitrogen derivatives, all of which are soluble in c.p. carbon disulphide. These hydrocarbons and their derivatives are practically innumerable and occur as complex mixtures, solutions, and emulsions. There are no known methods for separating and identifying all of the hydrocarbons and hydrocarbon derivatives present in bituminous materials, and in the routine examination of these materials none of the individual hydrocarbons are determined either qualitatively or quantitatively. There are a number of series or families of hydrocarbons, however, whose presence is readily detected by comparatively simple chemical tests. The various members of any given series possess many characteristics common to all, and the predominance of certain series therefore controls to a great extent the general characteristics and behavior of the bituminous materials in which they occur. For this reason it is essential that the highway engineer should acquaint himself with the properties of at least the more important hydrocarbon series if he wishes to use bituminous materials to maximum advantage. This involves an elementary knowledge of the variations in structure of hydrocarbon molecules.

Hydrogen (H) is the lightest known chemical element. It has an atomic weight of 1.01. A single hydrogen atom cannot combine with more than one atom of any other element. Its chemical affinity or valence is therefore one, and it is termed a monovalent element. It is an invariable

constituent of hydrocarbon molecules, and therefore of all bituminous materials. At very high temperatures it may be split off in an atomic or elemental state from hydrocarbon molecules, leaving behind a molecule richer in carbon, or else the element carbon itself. The hydrogen molecule is composed of two hydrogen atoms expressed H_2 or H − H. In the molecular state it is a rather inert, colorless, and odorless gas. In the atomic or nascent state, which it only transiently assumes, it is a powerful reducing agent or oxygen remover. In this capacity it unites with oxygen to form water. Oxidation, which is the opposite of reduction, may consist either in the addition of oxygen, its substitution for another element in a compound, or in the removal of hydrogen from a compound by means of oxygen or other oxidizing agent.

Carbon (C) has an atomic weight of 12.01, almost twelve times that of hydrogen. One atom of carbon can combine with four atoms of hydrogen, which is monovalent. Its chemical affinity is therefore four, and it is called a tetravalent element, altho with certain elements other than hydrogen it sometimes also exhibits a valence of two. It is a necessary constituent of hydrocarbon molecules, and therefore of all bituminous materials. Like hydrogen, at very high temperatures it may be split off in an atomic or elemental state from hydrocarbon molecules with the formation of lighter hydrocarbon molecules or the element hydrogen. Unlike hydrogen, it is non-volatile. It occurs as an element in three forms, as diamond, graphite, and amorphous carbon. This variation in form is believed to be due to different ways in which the carbon atoms are arranged in the carbon molecule, and the molecules in the masses. The amorphous form, as coke, lamp-black, or soot, is of most interest from the standpoint of bituminous materials. At ordinary temperature carbon is chemically inert, but at high temperatures it is a reducing agent and in this capacity unites with oxygen to form carbon dioxide or carbon monoxide.

Hydrocarbon Molecules exist in an almost infinite number of forms, some of which are exceedingly complex. The molecular weight of any hydrocarbon molecule is the sum of the atomic weights of hydrogen and carbon, each of which has been multiplied by the number of hydrogen and carbon atoms respectively which are present in the molecule. For all practical purposes the atomic weight of hydrogen is considered as 1 and the atomic weight of carbon as 12. Example: mol. wt. $C_2H_6 = (2 \times 12) + (6 \times 1) = 30$. The molecular weight of hydrocarbon molecules in general increases with the number of carbon atoms present in the molecule. No hydrocarbon molecule can contain more than 25.2 % hydrogen nor less than 74.8 % carbon. At ordinary temperature some hydrocarbon molecules are gases, some liquids, and some solids. At elevated temperatures many of the solid and liquid hydrocarbons assume the gaseous form without chemical change; also solid hydrocarbons may assume the liquid form without chemical change. At higher temperatures, depending upon individual hydrocarbons, molecules containing more than two carbon atoms may split into two or more different hydrocarbon molecules. When this occurs the original molecule is said to be cracked. If the cracking sets free the element carbon, the original hydrocarbon is said to be coked, and the operation involving such coking is termed destructive. If hydrocarbon molecules are subjected to elevated temperatures in the presence of air or oxygen, they may become oxidised. If they are subjected to elevated temperatures in the presence of hydrogen, they may be reduced. Cracking, coking, oxidising, and reducing reactions are produced in many

of the common manufacturing operations in connection with bituminous materials. They may also be produced during the manipulation of these materials in highway engineering. They frequently result in important and sometimes in injurious modification of the bituminous material involved, and for this reason they should be clearly understood by the highway engineer. They will be considered in detail later in this Section.

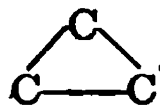
Hydrocarbon Radicals may be considered as hydrocarbon molecules from which have been removed one or more hydrogen atoms, leaving an equivalent number of free valences, which are extremely ready to unite with each other or with atoms which also carry free or unsatisfied valences. Thus three radicals may result from the removal of one, two, or three hydrogen atoms from the hydrocarbon molecule CH_4. The valence of these radicals is expressed by one, two, or three dashes placed after the radical formula, as follows: CH_3-, $CH_2=$, $CH\equiv$. Because of their extreme chemical activity, radicals can exist only transiently. They differ from true compounds in the fact that the latter carry no free valences, as all of the valences are satisfied within the molecule itself. Hydrocarbon radicals play an important part in determining just what compounds are ultimately formed in the processes of cracking, coking, oxidation and reduction of bituminous materials, as they are often produced as transient intermediate combinations of hydrogen and carbon during these processes.

Saturated Hydrocarbons are hydrocarbon molecules in which all adjacent carbon atoms are connected by not more than one valence, graphically shown as follows: $C-C$. Each valence not taken up by adjacent carbon atoms connects with or is satisfied by a hydrogen atom. Saturated hydrocarbons are quite stable and not prone to chemical changes. They therefore impart chemical stability to bituminous materials in which they occur, the extent of this stability depending upon the amount or proportion of saturated hydrocarbons present in the bitumen of the bituminous materials.

Unsaturated Hydrocarbons are hydrocarbon molecules in which at least two adjacent carbon atoms are connected by two or three valences, graphically shown as follows: $C=C$, $C\equiv$. Each valence not taken up by an adjacent carbon atom is satisfied by a hydrogen atom. It is evident that no two adjacent carbon atoms in a hydrocarbon molecule can be connected by four valences, because there would then be no valences available for hydrogen which is a necessary constituent of hydrocarbons. Unsaturated hydrocarbons are invariably less stable than saturated hydrocarbons because of the tendency of the double or triple bonds to break down to single bonds, thus producing radicals which unite with each other or with reactive atoms to form new molecules which are saturated. In general, the greater the number of unsaturated valences between carbon atoms the less stable becomes the compound. Unsaturated hydrocarbons therefore tend to produce chemical instability in bitumens or bituminous materials in which they occur, depending upon the proportion of unsaturated hydrocarbons and the extent of their unsaturation.

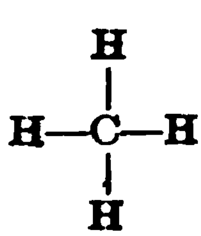
Open Chain Hydrocarbons are those in which the carbon atoms are linked to each other in such manner that their form may be graphically represented by an open chain, thus $C-C-C-C$. Side chains may also extend from any of the intermediate carbon atoms in the main chain, but in no case are the end carbon atoms of the same or different chains connected to form a closed chain or ring of carbon atoms within the molecule. Two or more adjacent carbon atoms in the open chain may be connected by more than one valence, so that open chain hydrocarbons may be either

saturated or unsaturated. Under certain conditions of temperature and pressure a number of unsaturated open chain hydrocarbon molecules may unite to form a single closed chain molecule. When this occurs it is at the expense of some or all of the multiple valences present in the reactive molecules which break down to a lesser number of valences between adjacent carbon atoms.

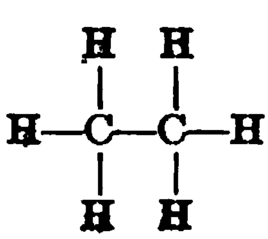
Cyclic Hydrocarbons are those in which some or all of the carbon atoms are linked in a closed chain, ring, or cyclic nucleus, thus . Open side chains of carbon atoms may extend from one or more of the carbon atoms which form a cycle, or a number of cycles may be linked together in a single molecule. Molecules which contain but one carbon cycle are known as monocyclic, those which contain two cycles are dicyclic. The general term polycyclic is applied to hydrocarbons which contain a number of cycles in the molecule. When two carbon cycles have a number of carbon atoms common to each other, the molecule is said to possess a condensed nucleus. If three carbon atoms are common to two cycles the molecule is sometimes called a bridge compound. In cyclic hydrocarbons two or more adjacent carbon atoms, either within the cycle itself or in a side chain attached to the cycle, may be connected by a double linkage. Cyclic hydrocarbons may therefore be either saturated or unsaturated. When the double linkage occurs in a side chain, chemical stability is usually less than when the double linkage is in the cycle. Under favorable conditions of temperature and pressure, cyclic hydrocarbons may break down into open chain hydrocarbons. The most common form of carbon cycle consists of six carbon atoms. No single cycles contain more than seven carbon atoms.

2. Open Chain Series of Hydrocarbons

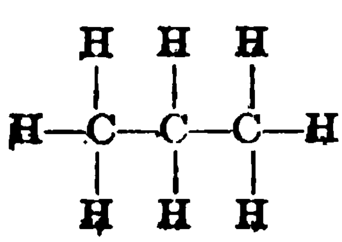
The Paraffin Series of hydrocarbons comprises the entire group of saturated open chain compounds. The general molecular formula for all of the members of this series is C_nH_{2n+2}. The simplest possible hydrocarbon and the only one which contains but a single carbon atom is the parent member of this series. Its name is methane and its simple molecular or empiric formula is CH_4. The next member containing two carbon atoms is ethane, C_2H_6; the third member, propane, contains three carbon atoms C_3H_8. Each succeeding member contains one more carbon atom and two more hydrogen atoms than the preceding member. This constant difference of CH_2 between adjacent members of a given series is common to all of the hydrocarbon series, which are therefore homologous. The graphic or constitutional formulas for the first three members of the paraffin series together with the monovalent, divalent, and trivalent radicals derived from each are as follows:



Methane CH_4



Ethane C_2H_6



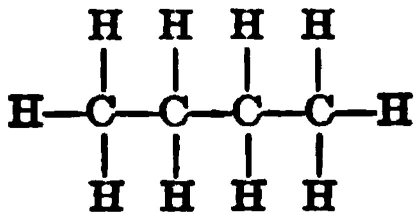
Propane C_3H_8

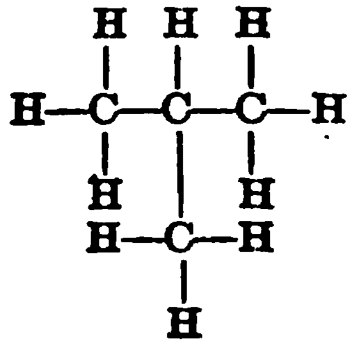
Radicals

Methyl $-CH_3$	Ethyl $-C_2H_5$	Propyl $-C_3H_7$
Methylene $=CH_2$	Ethylene $=C_2H_4$	Propylene $=C_3H_6$
Methenyl $\equiv CH$	Ethenyl $\equiv C_2H_3$	Propenyl $\equiv C_3H_5$

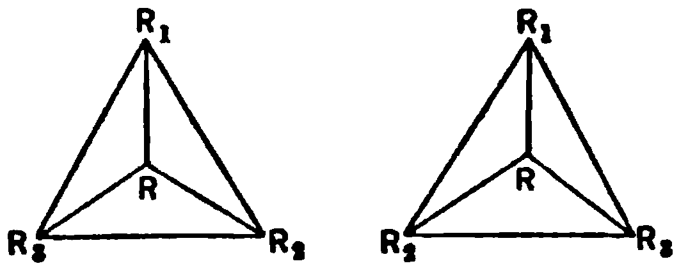
It will be seen that the nomenclature of the radicals is derived in all cases directly from the parent hydrocarbon, the ending yl being given to monovalent radicals, ylene to divalent radicals and enyl to trivalent radicals. Moreover, it may be seen that the members of this series, after methane, may be considered as combinations of two or more radicals. Thus ethane is composed of two methyl radicals linked together so that all valences are satisfied. Propane may be considered as a combination of the radicals methyl and ethyl or of two methyl radicals and one methylene radical. The first four members of the paraffin series are gases at ordinary temperature and pressure; the members containing from 5 to 15 carbon atoms are liquids, and those containing over 15 carbon atoms are solids. As the number of carbon atoms in the molecule increases certain other physical differences are found to exist. These differences are generally observed between the members of any given series (see Art. 4, RELATIONS EXISTING BETWEEN MEMBERS OF THE SAME SERIES). The paraffin hydrocarbons are more stable chemically than any other series. They are not acted upon by concentrated sulphuric acid, fuming sulphuric acid or nitric acid at ordinary temperatures. They are mutually soluble in one another. Thus, the solid paraffins are readily dissolved by the liquid paraffins of low molecular weight. The lighter liquid paraffins are not perfect solvents for the solid hydrocarbons of certain other series. For such compounds, however, the solvent action increases with the number of carbon atoms present in the liquid paraffin molecules. The solid paraffins unlike the solid members of other series are practically insoluble in a very cold mixture of alcohol and ether. This fact is made the basis of a method for determining the percentage of scale paraffin in bituminous materials. Paraffin hydrocarbons, both liquid and solid, are essentially greasy and exhibit but little cementitiousness. They predominate in certain petroleums. See Art. 15, PARAFFIN PETROLEUMS.

Isomerism. When two molecules or compounds contain the same elements in the same proportion but differ in structure or constitution, they are said to be isomeric and are termed isomers of one another. Isomerism exists to a marked extent among the hydrocarbons and plays an important part in the make-up and characteristics of bituminous materials. There are two forms of isomerism of particular interest: (1) Metamerism and (2) polymerism. In metamerism the isomers have the same molecular weight. In polymerism the isomers, while of the same percentage composition, have different molecular weights. Metamerism is a common phenomenon with nearly all of the paraffin hydrocarbons. The members of this series cannot polymerize, however, and polymerism will therefore be described under certain of the other series. The ordinary forms of metamerism may be graphically illustrated in formulas of two dimensions. Starting with the fourth member of the paraffin series, C_4H_{10}, the graphic formula may be represented in two ways.

1. 

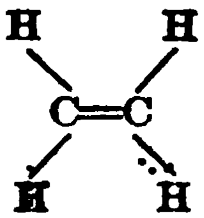
2. 

The first formula shows the single chain or normal constitution, while the second formula shows the introduction of a side chain. The first compound is known as normal butane; the second as isobutane. The essential difference lies in the relative position of the carbon atoms to one another, which modifies both the chemical and physical properties of the materials, altho both have the same empiric formula C_4H_{10}. The next hydrocarbon of the paraffin series, C_5H_{12}, has three isomeric forms and as the number of carbon atoms in the molecules increases the number of isomers rapidly multiplies. Thus the hydrocarbon, $C_{13}H_{28}$, has 802 isomers. As the known normal paraffins run as high as $C_{60}H_{122}$, it is evident that the possible isomers for this compound are almost beyond comprehension. Another form of metamerism which is of considerable interest involves the conception of a three-dimensional or asymmetric carbon atom which has the form of a tetrahedron. Each apex of the tetrahedron represents a valence. If different univalent atoms or radicals are attached to these valences it is possible to arrange them so as to obtain isomers. Thus with four radicals which may be represented by the letters R, R_1, R_2, and R_3 the following isomers may be produced:

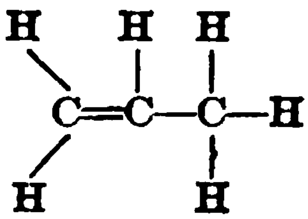


It is evident that from a given viewpoint R, the radicals are read in order from left to right or clockwise in the first illustration, while in the second they are read from right to left, or counter-clockwise. This form of isomerism is known as space or stereo isomerism. Many of the space isomers are optically active and when present in solution will rotate a beam of polarized light, passed thru the solution, to the right or to the left as the case may be. Those which rotate to the right are termed dextro rotatory and those which rotate to the left are termed laevo rotatory. Certain petroleums are optically active due to the presence of stereo isomers and this fact has been made the basis for identifying their source or origin. See Art. 13, FORMATION OF PETROLEUMS.

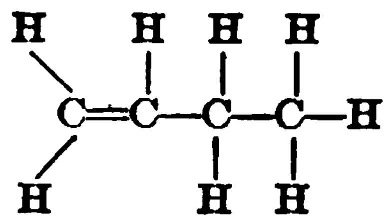
The Olefine or Ethylene Series of hydrocarbons comprise the open chain unsaturated compounds which contain one pair of adjacent carbon atoms connected by two valences. The general molecular formula for all members of this series is C_nH_{2n} and the common difference CH_2 exists between adjacent members. The first member of this series, ethylene, contains two carbon atoms, and its empiric formula is C_2H_4. The next member is propylene, C_3H_6. The graphic formulas for the first three members are as follows:



Ethylene C_2H_4



Propylene C_3H_6

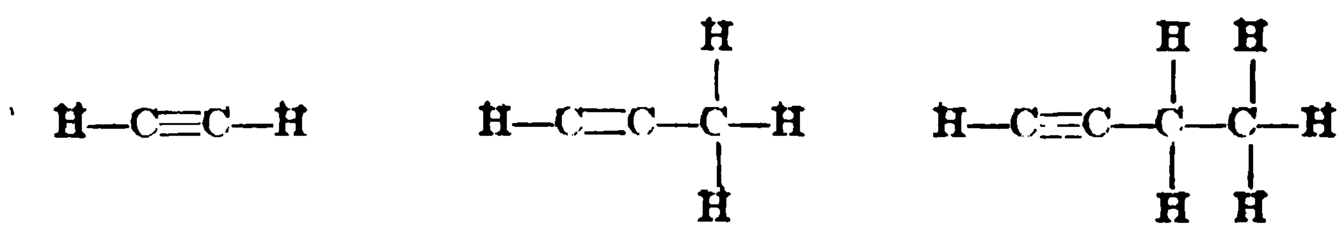


Butylene C_4H_8

It will be noted that the nomenclature of these compounds is identical with that of the divalent radicals of the paraffin series. Their relative structure should not, however, be confused, as the former are satisfied

molecules while the latter are merely partial compounds or collections of atoms which have free valences. Like the paraffins, the first few members of the olefine series are gases at ordinary temperature and pressure. The members containing from 5 to 20 carbon atoms are liquids and the higher members are solids. From the second member up isomerism occurs, as in the paraffin series, due to the introduction of side chains instead of a prolongation of the main chain of carbon atoms. In addition, the olefines exhibit the phenomenon of polymerism in which a number of molecules combine to form a single molecule. Thus three ethylene molecules polymerize to a single cyclic molecule containing six carbon atoms in the cycle, as follows: $3C_2H_4 = C_6H_{12}$. It is evident that the percentage of hydrogen and carbon in these two molecules is the same but that molecular formulas and molecular masses are different. These facts distinguish polymerism from metamerism (see Art. 2, ISOMERISM). Polymerism of hydrocarbons may be considered as isomerism of members of different series. The olefine hydrocarbons are much less stable chemically than are the paraffin hydrocarbons. They are readily acted upon and combine with sulphuric acid at ordinary temperature and may thus be separated from the paraffin hydrocarbons. They are mutually soluble in one another and are better solvents for the solid hydrocarbons of certain other series than are the corresponding members of the paraffin series. The solvent action of the liquid olefines increases with the number of carbon atoms in the molecule. The olefines are normal constituents of all petroleums but seldom if ever predominate in bituminous materials. The liquids and solids are essentially greasy and non-cementitious. The olefines are of particular interest, however, in the fact that by polymerization they produce hydrocarbons of other series which often predominate in bituminous materials of an asphaltic nature and possess certain desirable characteristics.

The Acetylene Series of hydrocarbons comprise the open chain unsaturated compounds which contain one pair of adjacent carbon atoms connected by three valences. The general molecular formula for this series is C_nH_{2n-2} and the common difference CH_2 exists between adjacent members. The first member, acetylene, which is a gas, has the empiric formula C_2H_2. Graphic formulas for the first three members are as follows:



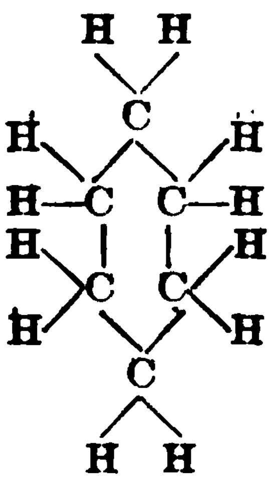
Acetylene C_2H_2 Allylene C_3H_4 Ethyl Acetylene C_4H_6

Metamerism exists among members of the acetylene series and like the olefines a number of molecules may polymerize to form a single molecule of another series. Thus three acetylene molecules will polymerize under suitable conditions to form a cyclic molecule containing six carbon atoms in the cycle as follows: $3C_2H_2 = C_6H_6$. The acetylene hydrocarbons are even less stable chemically than are the olefines. Like the olefines they are readily acted upon by sulphuric acid. They occur to only a very limited extent in bituminous materials but are of especial interest because by polymerisation they produce hydrocarbons of other series which predominate in tars and give to them peculiar characteristics essentially different from other types of bituminous materials.

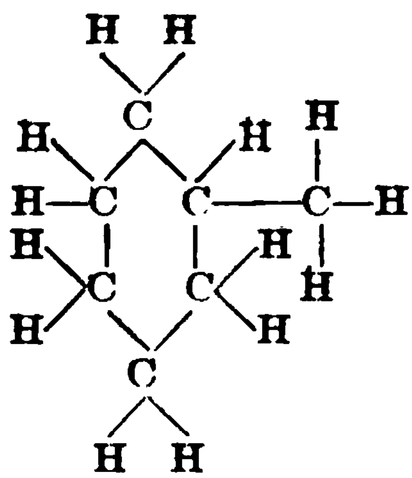
Other Unsaturated Open Chain Series. There are a number of other highly unsaturated and unstable open chain series which are of less importance than the foregoing. They are of interest, however, as being isomers of hydrocarbons in other series which predominate in certain bituminous materials. Among them may be mentioned the diolefines with the same general formula as the acetylenes C_nH_{2n-2}, the olefine acetylenes C_nH_{2n-4}, and the diacetylenes C_nH_{2n-6}.

3. Cyclic Series of Hydrocarbons

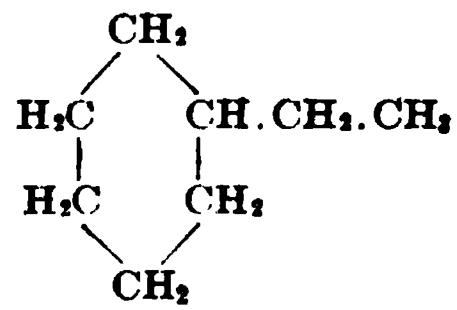
Monocyclic Polymethylenes. The monocyclic polymethylenes comprise a number of series of hydrocarbons which include all of the saturated monocyclic compounds. There are five of these series: the trimethylene series with three carbon atoms in the cycle; the tetramethylene series with four carbon atoms in the cycle; the pentamethylene series with five carbon atoms; the hexamethylene series with six carbon atoms; and the heptamethylene series with seven carbon atoms in the cycle. All of them have the general formula C_nH_{2n}, which is the same as that of the olefines. Of these series the hexamethylene is of most common occurrence and generally the most important. The hexamethylenes are commonly called NAPHTHENES and the first member of the naphthene series is termed hexamethylene or hexahydrobenzene. It has the empiric formula C_6H_{12}. The next member is C_7H_{14}, and each succeeding member differs from its adjacent members by CH_2. The graphic formulas for the first three members of the naphthene series are as follows:



Hexamethylene or Hexahydrobenzene C_6H_{12}



Hexahydrotoluene C_7H_{14}

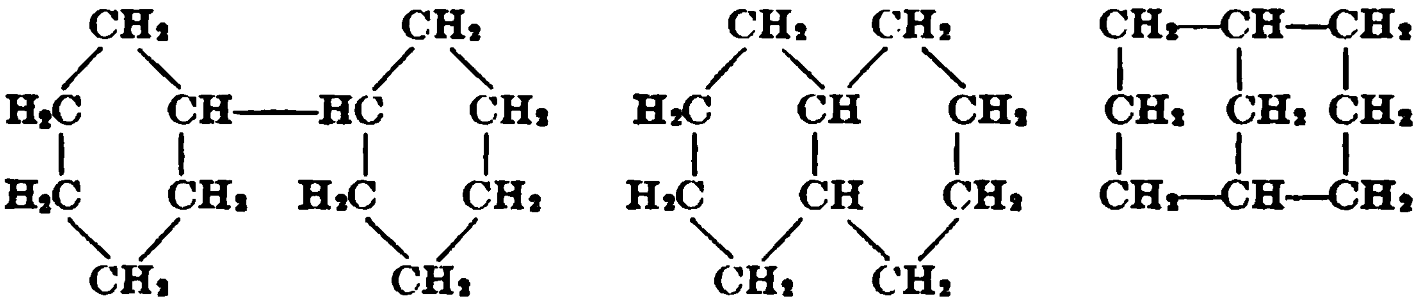


Hexahydroxylene C_8H_{16}

The known naphthenes are liquid hydrocarbons. Isomers are found from the third member up, but in the series proper isomeric modification occurs in the side chains and never results in a modification of the six carbon cycle or nucleus. The first member may be considered as being composed of six methylene radicals (see Art. 2, THE PARAFFIN SERIES) or as the result of polymerization of three ethylene molecules. Altho not so stable chemically as the paraffin hydrocarbons, the naphthenes are not acted upon by sulphuric acid as are the unsaturated open chain hydrocarbons. They are, however, broken up by the action of nitric acid, and it is believed that the higher members are readily acted upon at elevated temperatures by sulphur and oxygen (see Art. 20). They are mutually soluble in one another and are better solvents for the solid hydrocarbons of certain other

series than are the corresponding members of the paraffin series. Their solvent action increases with the number of carbon atoms in the molecule. The naphthenes are normal constituents of petroleums and occur to a marked extent in those of the semiasphaltic type. They are closely associated with those hydrocarbons which predominate in asphaltic petroleums and asphalts.

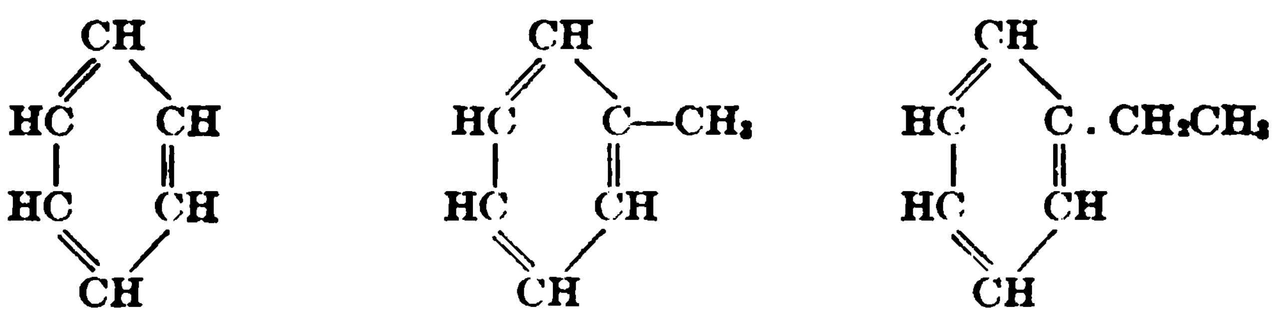
The Polycyclic Polymethylene Series include all of the various polymethylene series which contain two or more polymethylene nuclei. Their general formulas are C_nH_{2n-2}, C_nH_{2n-4}, C_nH_{2n-6}, etc. The nuclei may be individual and connected by a single valence or they may be condensed and have two or three carbon atoms in common. The following graphic formulas illustrate the three types above mentioned.



$C_{12}H_{22}$ $C_{10}H_{18}$ C_9H_{16}

The third formula represents a type of hydrocarbons which are known as bridge compounds. But little is known of the individual members of the polycyclic polymethylene series except that their structure is extremely complicated and that many of them possess unsaturated side chains which make them susceptible to the action of sulphuric acid without destroying the carbon nuclei. The bridge compounds in particular are believed to predominate in asphaltic petroleums and asphalts and to impart to these bituminous materials their cementitious character. Their chemical stability depends upon their degree of saturation. The higher solid members are soluble or may be fluxed with the heavier liquid members of the preceding series. Many of them, however, are insoluble in the liquid hydrocarbons of low molecular weight, particularly those of the paraffin series. This fact is made the basis of the determination of asphaltenes in petroleums and asphalts (see Art. 45).

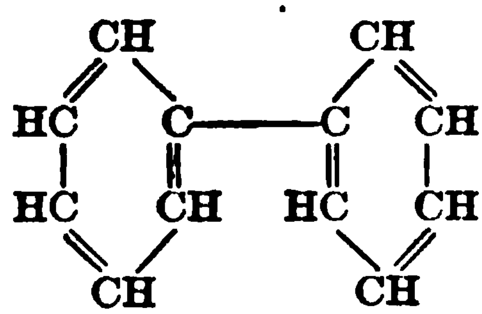
The Benzene Series of hydrocarbons have a structure analogous to that of the hexamethylenes or naphthenes. They are monocyclic, and the cycle, known as the benzene nucleus, contains six carbon atoms. Three double valences occur between adjacent carbon atoms so that the cycle is unsaturated. The general molecular formula for all members of this series is C_nH_{2n-6}. The common difference CH_2 exists between adjacent members. The first member is benzene C_6H_6. Its graphic formula, together with those of the next two members, is as follows:



Benzene C_6H_6 Toluene C_7H_8 Xylene C_8H_{10}

From the third member up isomers occur, there being four isomeric forms of xylene. Benzene may be considered as the product produced by the polymerization of three acetylene molecules in which the triple valences break down to double valences. It is also directly related to the naphthene series. By breaking down the double valences to single, and satisfying the free valences thus produced by hydrogen, the benzene becomes hydrogenized to hexahydrobenzene or hexamethylene. The nomenclature of the members of the naphthene series is thus established. A benzene molecule from which one hydrogen atom has been removed gives a monovalent radical called phenyl. While the benzene hydrocarbons are less stable chemically than the paraffins and naphthenes, the benzene nucleus does not readily break down. All of the series react with fuming sulphuric acid to form sulphonic acids in which the benzene nucleus is preserved. The lighter members of the benzene series are liquids and the higher members are solids at ordinary temperature. They are mutually soluble in one another and the lighter liquids are excellent solvents for most of the solid hydrocarbons of other series. This series occurs to a marked extent in tars. It is one of a number of series, known as aromatic hydrocarbons, which predominate in tars and give to them certain peculiar characteristics.

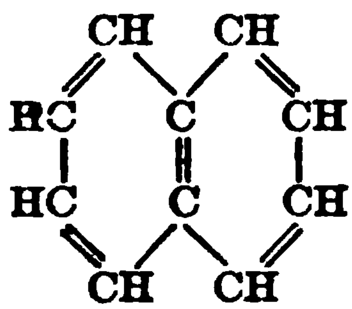
The Polyphenyl Series embrace a number of series of hydrocarbons whose members contain two or more phenyl radicals or benzene nuclei connected by single valences. The general formulas for these series are C_nH_{2n-14}, C_nH_{2n-16}, C_nH_{2n-18}, etc. The simplest type of hydrocarbon in the polyphenyl series is diphenyl, which is the first member of the dicyclic series or diphenyl series. Its graphic formula, which has its analogue in the dicyclic polymethylenes, is as follows:



Diphenyl
$C_{12}H_{10}$

The polyphenyls are normal constituents of tars but are of less importance than other polycyclic aromatic hydrocarbons, such as the naphthalene and anthracene series.

The Naphthalene Series of hydrocarbons contain a condensed nucleus composed of two benzene nuclei having two carbon atoms in common. Its general formula is C_nH_{2n-12}. Naphthalene, $C_{10}H_8$, is the first member of this series. Its graphic formula is as follows:

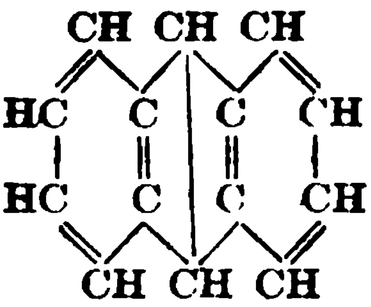


Naphthalene CH_{810}

Naphthalene itself deserves especial consideration because, of any single hydrocarbon, it probably occurs to the greatest extent in tars which are of interest in highway engineering. It is a white crystalline body which melts at 79° C (174° F) and boils at 218° C (425° F), but volatilizes readily at ordinary temperature. Altho solid, it is a powerful solvent or flux for the solid hydrocarbons of other series present in tars. The members of the naphthalene series are acted upon by concentrated sulphuric acid.

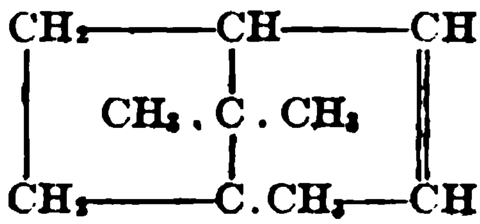
The Anthracene Series of hydrocarbons have a rather complicated condensed nucleus consisting of two unaltered and one altered benzene cycles, two carbon atoms being common to adjacent cycles. The general formula of this series is C_nH_{2n-18} and the graphic formula for its first member,

anthracene, is as given below: The members of the anthracene series are solids which occur mainly in tars. They are mutually soluble in members of the benzene and naphthalene series and are acted upon by concentrated sulphuric acid.



Anthracene $C_{14}H_{10}$

Other Unsaturated Cyclic Series. There are a number of other unsaturated cyclic series whose members occur in various bituminous materials. Many of them are solids which in mixture or solution with other fluid hydrocarbons impart cementitiousness to the mass. Some of them are of very complicated structure but are usually related in some way to the hexamethylene or benzene nuclei. As an example of this class may be mentioned camphene, whose graphic formula is as follows:



Camphene $C_{10}H_{16}$

This compound belongs to a group of hydrocarbons known as turpenes, which are present to a marked extent in resinous or rosinlike bodies. Members of the turpene group have been found in bituminous materials which possess cementitious qualities.

4. Interrelationship of Hydrocarbons

Relations Existing Between Members of the Same Series. Certain general relations exist between different members of any given series of hydrocarbons which are as a rule quite similar to the relations existing between members of any other series. The following rules are generally true for the normal members of a given hydrocarbon series, but the isomers sometimes create exceptions. (1) Members of a given series are usually completely soluble in one another. (2) As the number of carbon atoms in the molecule or the molecular weight increases, the specific gravity usually increases. (3) As the molecular weight increases, the coefficient of expansion decreases. (4) As the molecular weight increases, the liquefying temperatures of the gaseous hydrocarbons rise. (5) As the molecular weight increases, the boiling points of the liquid hydrocarbons become higher. (6) As the molecular weight increases, the melting points of the solid hydrocarbons become higher. (7) All members of a given series possess certain properties in common by which the series to which they belong may be identified. These relations greatly influence the relations between different grades of the same type of bituminous material as given under individual tests. See Arts. 32 to 48 inc.

Relations Existing Between Different Series. The interrelationship of certain hydrocarbon series has been shown to some extent in Arts. 1 and 2. All of the series are related to one another either directly or indirectly, and this fact has a most important bearing upon the production and manufacture of bituminous materials. These relations should be clearly understood in order to appreciate the similarities and differences existing in bituminous materials of different types and also the modifying effects produced by the various processes of manufacture and methods of manipulation. All hydrocarbons are composed of the same elements. The innumerable compounds, each possessing its own individual and peculiar characteristics, are merely the result of different structural combinations of hydrogen and carbon atoms in varying proportions and quantities. By breaking up the various structures and recombining the atoms or radicals

new compounds are formed. Thus members of one series under favorable conditions are transformed into members of other series. Paraffins may be broken down to olefines under suitable conditions of temperature and pressure. Olefines may polymerize to naphthenes and acetylenes to benzenes. Benzenes may be hydrogenized to naphthenes or condensed to naphthalenes and anthracenes. Naphthenes may be converted into polycyclic polymethylenes and benzenes and naphthenes may in turn produce turpenes. It is for these reasons that nature starting with the same identical raw material may produce in one case paraffin petroleum and in another asphaltic petroleum or asphalt. These are the reasons why, by artificial processes, two such unlike materials as bituminous coal and petroleum may be made to yield tars quite similar in character, and why certain petroleums may be made to yield asphalts. Comparatively little has been published upon the general interrelationship of bituminous materials from the standpoint of hydrocarbon chemistry. A great deal of information regarding members of the different series is, however, to be found in textbooks on organic chemistry.

CLASSIFICATION

5. Methods of Classification

Nomenclature. The nomenclature of bituminous materials is introduced at this point in order that the general relationship of materials and their properties may be understood and in order that the definitions may be readily accessible for consultation during the perusal of this Section. The following terms are arranged in groups according to a logical sequence rather than alphabetically. Those marked with an * have been adopted as standard by the American Society for Testing Materials; those marked with a ‡ have been recommended to the American Society for Testing Materials by the Committee on "Standard Tests for Road Materials"; and those marked with a † have been proposed to the American Society of Civil Engineers by the Special Committee on "Materials for Road Construction and Standards for Their Test and Use."

General Definitions

Bitumen.*† A mixture of native or pyrogenous hydrocarbons and their non-metallic derivatives, which may be gases, liquids, viscous liquids, or solids, and which are soluble in carbon disulphide.

Bituminous.* Containing bitumen or constituting the source of bitumen.

Bituminous Material.† Material containing bitumen as an essential constituent.

Liquid Bituminous Material.* One having a penetration at 25° C (77° F), under a load of 50 g applied for 1 sec, of more than 350.

Semisolid Bituminous Material.* One having a penetration at 25° C (77° F), under a load of 100 g applied for 5 sec, of more than 10, and a penetration at 25° C (77° F), under a load of 50 g, applied for 1 sec, of not more than 350.

Solid Bituminous Material.* One having a penetration at 25° C (77° F), under a load of 100 g applied for 5 sec, of not more than 10.

Bituminous Emulsion.‡ A liquid mixture in which minute globules of bitumen are held in suspension in water or a watery solution.

Flux.*† Bitumen, generally liquid, used in combination with a harder bitumen for the purpose of softening the latter.

Cut-Back Product.* Petroleum or tar residuum which has been fluxed with a distillate.

Petroleums

Petroleum.‡ Liquid bitumen, occurring as such in nature.

Topped Petroleum.‡ Petroleum deprived of its more volatile constituents.

Blown Petroleum.*† A semisolid or solid product produced primarily by the action of air upon a liquid native bitumen which is heated during the blowing process.

Asphalts

Asphalt.*† Solid or semisolid native bitumen, solid or semisolid bitumen obtained by refining petroleum, or solid or semisolid bitumen which is a combination of the bitumens mentioned with petroleums or derivatives thereof, which melts upon the application of heat and which consists of a mixture of hydrocarbons and their derivatives of complex structure, largely cyclic and bridge compounds.

Native Asphalt.* Asphalt occurring as such in nature.

Asphalt Cement.* A fluxed or unfluxed asphalt especially prepared as to quality and consistency for direct use in the manufacture of bituminous pavements, and having a penetration at 25° C (77° F) of between 5 and 250, under a load of 100 g applied for 5 sec.

Rock Asphalt.‡† Sandstone or limestone naturally impregnated with asphalt.

Tars

Tar.*† Bitumen which yields pitch upon fractional distillation and which is produced as a distillate by the destructive distillation of bitumen, pyrobitumen or other organic material.

Dehydrated Tar.*† Tar from which all water has been removed.

Refined Tar.*† Tar freed from water by evaporation or distillation until the residue is of desired consistency; or a product produced by fluxing tar residuum with tar distillate.

Coal Tar.*† The mixture of hydrocarbon distillates, mostly unsaturated ring compounds, produced in the destructive distillation of coal.

Gas-House Coal Tar.*† Coal tar produced in gas-house retorts in the manufacture of illuminating gas from bituminous coal.

Coke-Oven Tar.*† Coal tar produced in by-product coke ovens in the manufacture of coke from bituminous coal.

Oil-Gas Tar.*† Tar produced by cracking oil vapors at high temperatures in the manufacture of oil gas.

Water-Gas Tar.*† Tar produced by cracking oil vapors at high temperatures in the manufacture of carbureted water-gas.

Pitch.*† A solid residue produced in the evaporation or distillation of bitumen, the term being usually applied to residues obtained from tars.

Straight-Run Pitch.* A pitch run to the consistency desired, in the initial process of distillation, without subsequent fluxing.

Dead Oil.*† Oil with a density greater than water, which is distilled from tar.

Definitions Relating to Tests

Asphaltenes.*† The components of the bitumen in petroleum, petroleum product, maltha, asphalt cement, and solid native bitumen, which is soluble in carbon disulphide but insoluble in paraffin naphtha.

Carbenes.*† The components of the bitumen in petroleum, petroleum product, maltha, asphalt cement, and solid native bitumen, which is soluble in carbon disulphide but insoluble in carbon tetrachloride.

Free Carbon in Tar.*† Organic matter which is insoluble in carbon disulphide.

Fixed Carbon.*† The organic matter of the residual coke obtained upon burning hydrocarbon products in a covered vessel in the absence of free oxygen.

Normal Temperature.*† As applied to laboratory observations of the physical characteristics of bituminous materials, is 25° C (77° F).

Consistency.*† The degree of solidity or fluidity of bituminous materials.

Viscosity.‡† The measure of the resistance to flow of a bituminous material, usually stated as the time of flow of a given amount of the material thru a given orifice.

Penetration.‡ The consistency of a bituminous material expressed as the distance that a standard needle vertically penetrates a sample of the material under known conditions of loading, time and temperature. When the conditions of test are not specifically mentioned, the load, time and temperature are understood to be 100 g, 5 sec, 25° C (77° F), and the units of penetration to indicate hundredths of a centimeter.

Main Divisions. As the term bituminous is used not only in connection with materials consisting of or containing bitumen, but also with materials constituting the source of bitumen, two main divisions of bituminous materials are thus established. The two divisions are distinguished by the fact that members of the former are either wholly or to a considerable extent soluble in carbon disulphide, while members of the latter are not.

Materials Consisting of or Containing Bitumen may, from the standpoint of highway engineering, be divided into two groups: (1) Petroleum and asphalt products; (2) tar products. They may also be classified according to the use for which they are best suited, such as dust palliatives, carpet or mat building materials, and materials incorporated in the wearing course proper during construction. The most logical method, however, is to classify them under the headings: (1) Native bitumens and bituminous materials, and (2) artificial and refined bitumens and bituminous materials. This method has been followed in Arts. 6 and 7.

Materials Constituting the Source of Bitumens and Bituminous Materials vary greatly in character. The term bituminous is not customarily applied to all of these materials but mainly to that class of substances known as pyrobitumens. Thus wood, if destructively distilled, is the source of certain bitumens, but it is not ordinarily termed a bituminous material. On the other hand, coal, which, if destructively distilled, will produce bitumens, is termed bituminous coal. Bituminous coal is a pyrobitumen and from the standpoint of highway engineering is the only one of any great importance. It is therefore unnecessary to further classify the pyrobitumens except to state that they are produced in nature either by the direct metamorphosis of vegetable matter or else by the action of heat upon the bitumens themselves. In the latter case they are called indurated bitumens or asphaltic coals.

6. Native Bitumens and Bituminous Materials

Classes. The native bitumens and bituminous materials divide themselves according to their physical state into three main classes: gases,

liquids, and solids. No absolutely sharp distinction can be made between the liquids and solids because of an intermediate class known as semisolids, which gradually merge from the extremely viscous liquids to the harder solids. It is, however, customary to consider most of the semisolids with the solids. This method has been adopted in the following classification. In this classification certain materials which are only indirectly of interest in highway engineering have been included. Those which are of most importance are considered in detail in subsequent articles.

Gases. The two native hydrocarbon gases of interest are:

1. Marsh gas, mostly methane, formed by the decomposition of vegetable matter under water;

2. Natural gas, mostly C_nH_{2n+2} hydrocarbons, formed under similar conditions to petroleum and often accompanying it.

Fluids. The fluid native bituminous materials embrace the petroleums and malthas. The petroleums run from thin fluids to those which are very viscous and almost semisolid. There are two well-defined classes of petroleums, paraffin and asphaltic. There is also an intermediate class commonly termed semiasphaltic. In the following classification the malthas are included under the extremely viscous asphaltic and semiasphaltic petroleums:

1. Paraffin petroleums, consisting principally of C_nH_{2n+2} hydrocarbons, which series predominates among the solid hydrocarbons held in solution;

2. Asphaltic petroleums, consisting principally of cyclic hydrocarbons of the C_nH_{2n}, C_nH_{2n-2}, C_nH_{2n-4}, etc, series. The unsaturated polycyclic series predominate among the solid hydrocarbons held in solution to the practical exclusion of paraffin hydrocarbons. When these petroleums are very viscous and are found impregnating porous rock to the extent of not over 25%, the entire mass of bituminous rock is often called rock asphalt;

3. Semiasphaltic petroleums containing a considerable proportion of fluid and some solid C_nH_{2n+2} hydrocarbons; but also carrying a large amount of cyclic C_nH_{2n}, C_nH_{2n-2}, C_nH_{2n-4}, etc, hydrocarbons, the unsaturated polycyclic series predominating among the solid bodies held in solution.

Solids. The solid native bituminous materials divide themselves into two main classes, paraffin and asphaltic. The latter only are of importance from the standpoint of highway engineering.

1. Paraffin bodies with distinctive names such as ozocerite and hatchettite, consisting mainly of C_nH_{2n+2} hydrocarbons, probably produced in nature from paraffin petroleums.

2. Asphaltic bodies consisting almost entirely of cyclic hydrocarbons of the C_nH_{2n}, C_nH_{2n-2}, C_nH_{2n-4}, etc, series. These substances range from semisolids to hard brittle black minerals somewhat resembling coal in appearance. The unsaturated polycyclic hydrocarbons predominate but vary considerably in their relative proportions. Many of them carry high percentages of mineral matter, and when this is in excess of the bitumen they are often termed rock asphalts. The solid asphaltic bitumens are soluble in or may be fluxed with the liquid bitumens. They have probably been produced in nature from asphaltic petroleums and with some few exceptions are called asphalts. Some of them have distinctive mineralogical names such as gilsonite and grahamite.

7. Artificial and Refined Bitumens and Bituminous Materials

Groups. The artificial and refined bitumens and bituminous materials of direct interest in highway engineering can be most conveniently grouped and classified according to their derivation and method of production. Of the following divisions, group A consists of crude artificial bitumens whose refined products are covered by group C. Group B covers refined products of the fluid native bitumens, group D of the solid native bitumens, and group E covers refined mixtures of members of group A with the native products. Group F covers bituminous emulsions.

A. Materials Derived from the Destructive Distillation of Bitumens and Pyrobitumens which consist of a mixture of liquid hydrocarbons are called tars. Those of most importance are as follows:

1. **Water-gas tars** produced from petroleums or petroleum products in the carburation of water-gas, which are thin liquids consisting mainly of unsaturated cyclic hydrocarbons of the C_nH_{2n-6}, C_nH_{2n-12}, C_nH_{2n-18}, and similar series.

2. Coal tars produced in the manufacture of gas or coke from bituminous coal, usually viscous liquids consisting mainly of hydrocarbons of the C_nH_{2n-6}, C_nH_{2n-12}, C_nH_{2n-18}, and similar series together with their oxygen and nitrogen derivatives.

B. Materials Derived Primarily from the Fractional Distillation of Fluid Native Bitumens include the following refined products:

1. Petroleum distillates which are thin fluids.
2. Petroleum residues which may be
   Fluid residual oils,
   Asphalt cements,
   Refined asphalts.

C. Materials Derived Primarily from the Fractional Distillation of Tars include the following products:

1. Tar distillates which are thin fluids.
2. Tar residues which may be
   Fluid refined tars,
   Semisolid refined tars,
   Tar pitches.

D. Materials Derived Primarily by Refining and Fluxing Solid Native Bitumens and Bituminous Materials include the following:

1. Refined native asphalts.
2. Asphalt cements.

E. Mixtures of Tar and Petroleum or Asphalt Products are known as tar-asphalt compounds and usually vary from fluid to semisolid consistency.

F. Bituminous Emulsions are mixtures of bitumens with soap solutions, the resulting products thus being made readily miscible with water. They include:

1. Petroleum emulsions.
2. Asphalt emulsions.
3. Tar emulsions.

8. Classification According to Purpose for Which Used

Uses in Highway Engineering. Bituminous materials are used in a variety of ways in the treatment and construction of highways, the more important being as dust palliatives, in the construction of bituminous

mats or carpets, in the highway structure proper, as fillers, as fluxes and as impregnating materials. In the following classification are given those materials which are ordinarily used for the purposes above mentioned:

Dust Palliatives include crude fluid petroleums, heavy petroleum distillates, topped or partially distilled petroleums, petroleum emulsions, crude tars, partially dehydrated tars, fluid refined tars and tar emulsions.

Materials for Surface Mats or Carpets include viscous fluid residual petroleums, fluid cut-back asphalts, asphalt emulsions, viscous refined tars and viscous tar-asphalt mixtures.

Matérials for Incorporation During Construction include cut-back asphalts, asphalt cements, asphalt emulsions, very viscous refined tars, soft tar pitches and very viscous tar-asphalt mixtures.

Fillers include certain types of asphalt cements and tar pitches.

Fluxes include petroleum distillates (cutting-back fluxes) and viscous fluid residual petroleums.

Impregnating Materials for Wood Block include heavy tar distillates (creosoting oils) and mixtures of tars with tar distillates.

REFINING PROCESSES

9. Removal of Non-Bituminous Impurities

Sedimentation. With few exceptions crude bituminous materials, both native and artificial, contain impurities of a non-bituminous nature. In the crude state they are seldom adaptable for direct use in highway engineering and are usually subjected to purification and refining processes. Water is the most common impurity in both fluid and solid bituminous materials. Mineral matter, vegetable matter and occluded gases are other naturally occurring impurities. As most of these impurities are not soluble in the bitumen proper and as they differ from the bitumen in specific gravity, they may be removed wholly or in part by the process of sedimentation or separation by gravity. In the more fluid bituminous materials natural sedimentation occurs during storage. In the viscous fluids and solids heat is required to make the bitumen sufficiently liquid to allow the separation to take place. Water and mineral matter are the common impurities of petroleums. Upon standing in large storage tanks both settle to the bottom, leaving the practically pure bitumen above. The mineral matter consists of silt and sand called bottom settlings or B. S. Very viscous petroleums persistently retain a small amount of water which may be removed during the early stages of distillation if it is to be distilled. In many cases it is more expeditious to remove it by topping the oil, in what is known as a topping plant, before charging it into the still. In some cases storage tanks are fitted with steam coils by means of which the oil is warmed to a state of fluidity which facilitates the settlement of impurities. Water and free carbon are the common impurities of crude tars. The water may to a great extent be removed during storage, in which case it rises to the surface owing to the heavier gravity of the tar bitumen. The free carbon permeates the tar in a very finely divided state and can not well be removed except by filtration under pressure. This is seldom resorted to. The free carbon therefore appears in the refined tar. A small amount of water almost invariably remains in the tar and this may be removed during distillation or by a special dehydrating treatment previous to distillation. Solid native bitumens, if they contain impurities, have to be heated to a rather high temperature before they become sufficiently

fluid to separate from these impurities. In order to prevent local overheating they are usually agitated. Water and gases are driven off during the process. Some mineral matter settles out and the larger fragments of vegetable matter rise to the surface and are skimmed off. The mineral matter is sometimes so finely divided that it will not readily settle out and agitation further hinders separation. Both finely divided mineral matter and vegetable matter therefore commonly occur in the refined asphalt, altho to a lesser extent than in the crude.

Dehydration. Dehydrating processes are designed primarily for the removal of water in bituminous materials which will not completely separate water by sedimentation. It is desirable to do this prior to distillation because of the fact that the presence of water creates a tendency to foam when the mass of bituminous material is heated to about the temperature of boiling water. This makes it a troublesome and expensive procedure to remove water by distillation. Many dehydrating devices have been invented for use with petroleums and tars. The one in most common use for petroleum is known as a topping plant. In this device the oil is pumped under pressure thru a length of pipe containing a great many abrupt bends so that the path of the oil is exceedingly devious. The pipe work is set in a furnace so that it may be suitably heated. As the oil under pressure passes thru this pipe it is heated to a temperature above that of boiling water. This pipe discharges in a spray thru a loaded valve into a large expansion chamber where the water and more volatile constituents separate in the form of vapor which is condensed in a coil for the recovery of the light hydrocarbons. The hot oil passes thru another pipe direct to the still or storage tank. One of the most successful methods for dehydrating viscous tars is to cause the tar to flow in thin films over heated baffle-plates placed in an air-tight chamber to which vacuum is applied. Here the water and more volatile constituents volatilize without causing the tar to foam dangerously and the volatile products are then carried thru a condensing system where the light oils condense and separate by gravity from the condensed water. The dehydrated tar passes out thru another opening to the still or storage tank.

10. Distillation

Fractional Distillation is that form of distillation in which the original constituents of a mixture are separated mechanically and without chemical change. When a large number of compounds are present in a liquid mixture or in solution and the boiling points of many of these compounds are quite close together, it is impossible to separate the individual constituents, even qualitatively, by a single distillation. This is due to the fact that a relatively small quantity of the higher boiling constituents is mechanically carried over with the vapor of the low boiling constituents and in like manner a relatively small quantity of the lower boiling constituents is mechanically entangled and held back by the higher boiling constituents. If, however, fractions of the distillate are made within comparatively narrow temperature limits, as indicated by the temperature of the vapor emerging from the still, cuts will be obtained which carry a preponderance of those constituents whose true boiling points come within the limits observed. A refractionation of the individual cuts will then result in a further and more complete separation of the constituents. Petroleums and tars are usually subjected to fractional distillation in the manufacture of bituminous materials of interest in highway engineering. As both are

mixtures or solutions of a great many hydrocarbons, no attempt is made to recover individual constituents by a single distillation. The distillation is usually made upon the crude product which has been partially separated from its impurities by sedimentation or dehydration. All distillation operations involve apparatus or equipment consisting of at least three basic units: (1) A still or receptacle in which the material is heated; (2) a condenser in which the vapors coming from the still are condensed; (3) a receiver in which the condensed products are caught. In the distillation of petroleums and tars two main classes of products are obtained: (1) Distillates which pass over into the receiver; and (2) residues which remain in the still. The former, with a few exceptions, are of comparatively little interest from the standpoint of highway engineering. The residues, however, often constitute the materials directly used in the treatment or construction of highways. These residues vary in character and usefulness, to a very great extent depending upon the main object of the manufacturer in making the distillation. If he is working primarily for distillates the character and quality of the residues for highway purposes are often greatly impaired and sometimes ruined (see Art. 10, CRACKING). The shape and size of stills used in refining petroleums and tars vary to a considerable extent but they are usually cylindrical and are either partially or wholly bricked in. More detailed descriptions will be found in Arts. 19 and 28. Many of the heavier hydrocarbons suffer chemical change at temperatures lower than their boiling point. They can not therefore be fractionally distilled without breaking down into new compounds, unless means are devised to remove them at a lower temperature. In the manufacture of bituminous materials for highway work it is often necessary to remove certain of these compounds from the residues without allowing them to break down into other less desirable hydrocarbons, some of which would remain in the still. There are two methods of securing the desired results: (1) Distillation under reduced pressure, known as vacuum distillation; (2) distillation with live steam. In the former the normal boiling points of all of the hydrocarbons are lowered under the reduced pressure to such an extent that many of those which would otherwise break down before vaporizing pass over readily into the distillate at the lower temperature. In the distillation with steam, which is more commonly employed, the heavier hydrocarbons are mechanically carried over into the distillate in large quantities at temperatures much lower than their normal boiling points by the large volume of steam that is continuously injected into the liquid mass during distillation. The use of steam of course results, for the same reason, in cuts or distillate fractions, whose constituents show a wider range of boiling points. In the distillation of tars air is often used in place of steam. The oxygen of the air reacts to some extent with the hydrocarbons present so that the resulting distillation cannot be said to be strictly fractional. This action is, however, extremely slight in comparison with that produced by the action of air upon petroleums during distillation (see Art. 11, BLOWING). In the fractional distillation of petroleums and tars the cuts in the distillates may be made either according to the temperature as registered by a thermometer placed in the vapor before leaving the still or according to the gravity of the distillate as it comes from the condenser. The latter method is that ordinarily used. At just what points cuts are made depends upon how the manufacturer intends to dispose of his distillates and what refined products he wishes to make of them. Many distillates are further refined by refractionating them and subjecting them to chemical purification (see

Art. 10, TREATMENT OF DISTILLATES). Some water usually accompanies the low boiling and light gravity distillates unless the original material has previously been very thoroly dehydrated. This water readily separates by gravity from the hydrocarbon distillate, which is considerably lighter. In the case of steam distillation, water also accompanies the heavier and higher boiling hydrocarbon distillates. As distillation progresses the specific gravity of the distillate becomes greater. Petroleum distillates are, however, always lighter than water, no matter how far the fractional distillation is continued. On the other hand the heavier tar distillates weigh considerably more than water. The residue remaining in the still, while always fluid at the distilling temperature, if cooled to normal temperature will be found to become more and more viscous and as distillation progresses to pass thru the semisolid to solid state. When highway materials are being primarily produced samples of the residue are withdrawn from time to time, cooled and tested for consistency. The distillation is stopped when the desired consistency has been obtained. Owing to the fact that the large mass of material in the still retains its heat for a long time, a certain amount of distillation continues even after the fires have been drawn. This makes it necessary to draw the fire some time before the desired consistency of the refined product has been reached. Experience soon demonstrates just when to draw the fire for the production of a desired product from any given material.

Cracking. The term cracking is used to designate the process of splitting up a hydrocarbon or hydrocarbons into other hydrocarbons by the action of heat. The cracking of any given hydrocarbon usually results in the formation of at least one other hydrocarbon which carries a higher percentage of carbon than did the original, and therefore at least one which carries a lower percentage of carbon and a higher percentage of hydrogen. If cracking occurs during fractional distillation, this results in the production of a distillate of lower gravity and boiling point than that which would have been produced had the operation been purely fractional. In addition, it almost invariably results in the formation of hydrocarbons more unsaturated than the original hydrocarbon which is cracked. This has a most important bearing upon the character of both distillate and residue as compared with those obtained from the same material by purely fractional distillation. Many hydrocarbons crack at a temperature lower than their boiling points and many of those which normally boil and distil unaltered will crack if suddenly subjected to a temperature higher than their normal boiling point. Distillation of petroleums and tars under reduced pressure or with live steam agitation materially reduces but does not entirely prevent cracking, so that absolute fractional distillation is seldom attained. Distillation of the heavier hydrocarbons at normal pressure and without agitation promotes cracking, and if carried on under increased pressure cracking is greatly increased. It may also be increased to a marked extent by causing condensation of the vapors within the still itself whereby the condensed hydrocarbons fall back upon the residual mass which is at a considerably higher temperature than their boiling points. This may be accomplished by exposing the upper part of the still in such manner that it is considerably cooler than the lower portion. Banking the fire under a still during distillation also produces a similar effect. Unless agitation of some sort is utilized during distillation that portion of the material in contact with the still bottom will become overheated to such an extent that cracking and even coking will be induced. This is

not only true of distillation but also of any other heating process where direct fire or very hot gases are the source of heat. As the very low boiling, low gravity distillates are often the most valuable and as the percentage obtainable from a given bituminous material may often be materially increased by cracking, such process may be purposely employed by a manufacturer who is working primarily for distillates. On the other hand, if a desirable residue is the principal product to be manufactured, cracking is studiously avoided (see Art. 10, FRACTIONAL DISTILLATION), and extraordinary methods are employed to reduce it to a minimum. This is due to the fact that cracked residuums are extremely unstable and it is almost impossible to accurately control their consistency and other physical properties.

Destructive Distillation is that in which a material is distilled until only coke remains as a residue in the still. In the refining of petroleums and tars this process is only employed when it is desired to obtain the maximum quantity of distillate and the production of a bituminous residuum is not required. As applied to bituminous materials it is of interest only in connection with the formation of tars, or distillates which upon being fractionally distilled will yield pitches. From this standpoint it is considered in detail under Art. 25.

Treatment of Distillates. Petroleum and tar distillates used in highway engineering are not ordinarily subjected to further refining processes after they have once been collected except in the case of some petroleum distillates which are chilled and filtered to extract the more valuable solid paraffins. Those which are not directly of interest in highway work are, however, often further refined by refractionation and treatment with concentrated sulphuric acid. The acid treatment is used to remove the undesirable unsaturated hydrocarbons which usually contain an unsaturated open chain. These hydrocarbons react with the acid to form sulphonic acids which are practically insoluble in the distillate itself and which because of their higher gravity separate readily from the distillate. Sulphuric acid also precipitates certain heavier hydrocarbons which are believed to be held in colloidal solution and in addition promotes the polymerization of certain hydrocarbons to compounds somewhat similar to those left in the residuum from the original distillation. The acid treatment is made in a cylindrical lead-lined agitator with a conical bottom into which the heavier sulphonic acids settle. Agitation or diffusion of the acid thruout the body of distillate is usually secured by means of an air blast injected at the bottom of the agitator. After treatment the sludge acid is withdrawn and diluted with water, which breaks up the sulphonic compounds and sets free the hydrocarbons which had combined with the acid. These hydrocarbons separate by gravity from the diluted acid and are sometimes recovered, in which case they are known as acid sludge. Sometimes this acid sludge, which still contains some acid, is semisolid. The acid may be neutralized and removed by the action of a solution of caustic soda and the sludge then distilled. The residual acid sludges then resemble in some respects the residuums obtainable from the material originally distilled. These sludge residuums from petroleum distillates are of interest as having been used in some instances as a material of highway engineering.

11. Oxidation

Sulphurizing. If, during distillation of a petroleum, sulphur is thrown into the still, hydrogen sulphide gas, H_2S, is copiously evolved and a much

greater percentage of residuum of a given consistency is produced than could have been obtained by straight distillation. This is due to the removal of hydrogen from certain hydrocarbon molecules, thus producing radicals which unite to form much heavier and less volatile hydrocarbons. The residuums thus produced vary in certain characteristics from residuums of the same consistency produced by fractional distillation. In addition to the removal of hydrogen, which is known as an oxidizing reaction, the sulphur may also react with some of the hydrocarbons to form sulphur derivatives, or hydrocarbon molecules which contain sulphur. The former reaction is, however, the more important. The sulphurizing process was at one time quite extensively used but has been largely abandoned since it has been found that blowing air thru heated petroleum produces much the same results.

Blowing. In the blowing process air is forced thru the hot petroleum so as to cause violent agitation. The oxygen of the air then removes hydrogen from certain hydrocarbon molecules and forms water which passes off in the form of vapor. Like sulphur it may also combine to a slight extent with certain hydrocarbons to form hydrocarbon derivatives containing oxygen. As a rule the blowing process is conducted only upon viscous or semisolid petroleum residuums. It results in increasing the consistency of the residuum without material loss in weight or change in gravity. The reaction proceeds most vigorously at a temperature of over 205° C (400° F) and the heat of the reaction is then of sufficient magnitude to maintain the residuum in a fluid state without the application of external heat. Considerable care is required to keep the residuum at a temperature lower than its flash point, or otherwise the injection of copious quantities of air is apt to cause spontaneous combustion. The formation and distinguishing characteristics of blown petroleums are given in Art. 20.

12. Fluxing

Fluxing with Residuals. The solid native bituminous materials are usually too hard to be used directly in highway engineering. After preliminary refining, consisting of the partial or complete removal of impurities, they are softened to the desired consistency by combining or fluxing them with fluid or relatively soft petroleum residuums. Solid petroleum residuums may also be softened in the same manner. The fluxing process is ordinarily conducted in an open tank or kettle which may be equipped with steam coils or heated direct. The hard residuum is first melted in the kettle, after which a sufficient amount of the heated petroleum residuum or flux is run in so as to produce a finished product of desired consistency. Rather prolonged agitation of the contents of the kettle is required to secure an absolutely uniform product. Such agitation may be obtained by means of a mechanical stirring device, or by agitation with steam or air. Mechanical agitation is preferable in certain respects but is not as efficient as the other two methods. Agitation with steam is desirable from many standpoints but invariably results in the mechanical removal of some of the lighter constituents present. Air agitation on the other hand causes some oxidation to take place, altho the temperatures employed are not as high as that at which such oxidation becomes very pronounced. In both steam and air agitation, however, some allowance, in the proportion of flux to be used, should be made for unavoidable hardening. In general the proportion of flux used is considerably less than for the material fluxed. In some

cases, however, a large proportion of soft blown petroleum residuum may be hardened or reinforced to the desired consistency by incorporating with it a relatively small amount of a harder bituminous material.

Fluxing with Distillates. Distillates are sometimes used as fluxes for the harder bituminous materials, which are then said to be cut-back. The term cutting-back was originally applied to the practice of first distilling a bituminous material until the residuum was hard and brittle in order to obtain certain valuable products from the heavier distillates, after which a portion of the distillate was run back or incorporated with the hard residuum to bring it to the desired consistency. It has, however, gradually come to be used to denote the use of a distillate as a flux for any natural or artificial residuum.

Emulsification. All bitumens are practically insoluble in water. By mechanical agitation some of them may be temporarily emulsified with water, all but a small portion of which soon separates by gravity. If, however, a strong solution of soap is used the soap acts as a medium for holding the bitumen and water together in suspension or emulsion and, if properly made, such emulsion may be further mixed or diluted with water without causing separation. Dilute bituminous emulsions are nevertheless in a delicate state of equilibrium and often ready to separate upon slight provocation. Emulsions of petroleums, asphalts and tars may be obtained under suitable conditions. Sometimes instead of using a manufactured soap, manufacturers of bituminous emulsions first combine the bitumen with an animal or vegetable oil or fat and then saponify the mixture by means of caustic soda, potash or ammonia.

PETROLEUMS

13. Origin of Petroleums

Occurrence of Petroleums. Petroleums are fluid native bitumens widely distributed over the earth. They are known as mineral oils in contradistinction to those occurring in animal and vegetable matter. Their name is derived from the Latin words " petra," rock, and " oleum," oil, and they are usually found within rock formations. History records a knowledge of their occurrence as early as 450 B.C. at Kirab, Persia. Altho they originally occur in rock formations, their seepage to the surface of the earth thru natural rock crevices is not uncommon. They are not usually collected in paying quantities from such sources however. They are commonly found in large quantities below the earth's surface at depths varying from 50 to 4000 ft and over. They are not limited to any particular geological horizon but are found in rocks of all ages from the lower Silurian to the most recent. They are frequently accompanied by water and natural gas. They are generally obtained by boring into the rock formation in which they occur. The deposits are almost invariably under pressure, sometimes as high as 600 lb per sq in, and this pressure forces them to the surface for some time after the deposit has been struck. These deposits are termed oil wells but the petroleum does not occur as a well or subterranean lake. It usually impregnates a porous stratum of rock such as sandstone or conglomerate overlaid with shale or slate which serves as a natural seal and prevents the oil from seeping to the surface of the earth. In exceptional cases it is found in immense sandstone lenses embedded in an impervious rock. The natural requirements for its collection in quantities of commercial importance are generally believed to depend upon the

structural theory which is based upon its common occurrence in anticlinal or rock arch areas (see Art. 14, MINING OF PETROLEUM). First, there must be a porous reservoir rock such as sandstone, or otherwise the petroleum will remain more or less permanently scattered thruout crevices in the rock formation. Second, there must be an impervious stratum above the porous reservoir rock or else the natural pressure or infiltrating water will cause the oil to percolate to the surface. Third, there must be water within the porous reservoir rock which, being of higher gravity than the oil, will seek a lower level and settle into structural troughs or synclines. If water is not present the oil itself will tend to collect in synclines. Fourth, there must be an anticlinal fold in which by force of gravity the oil in separating from the water will accumulate. If there are no anticlinal folds or arches the oil will gradually percolate up the dip of inclined strata to the point of ingress of the water. There are certain modifications of the anticlinal theory, such as the arrested anticline or terrace, which have been advanced to account for the accumulation of petroleum in localities where the anticlinal structure proper is lacking. Nearly all of these theories, however, involve an impervious arch formation of one sort or another.

Formation of Petroleums. Altho petroleums are of mineral occurrence they are composed of mixtures of a great number of organic compounds consisting mainly of hydrocarbons. A number of theories have been advanced as to their origin and it is doubtful if any single theory can be made to satisfactorily explain the formation of all petroleums. The theories fall into two general classes: those which consider petroleums to be of inorganic origin, and those which consider them to be of organic origin. According to the inorganic theories the formation of hydrocarbons is explained by (1) the action of thermal waters and acids upon carbonate rocks under great pressure, and (2) the action of water upon large masses of metallic carbides, which are believed to have been formed in the interior of the earth. The second theory has received more support than the first. It is well-known that calcium carbide is decomposed by water with the liberation of the hydrocarbon gas acetylene, according to the following reaction, $CaC_2 + 2H_2O = Ca(OH)_2 + C_2H_2$. In like manner aluminum carbide reacts with water to form methane, which is a constituent of natural gas, $Al_4C_3 + 12H_2O = 4Al(OH)_3 + 3CH_4$. There are a number of carbides of iron which react with water to form hydrocarbons and these reactions may be expressed by the equation, $3Fe_mC_n + 4_mH_2O = mFe_3O_4 + C_{3n}H_{8m}$. There are reasons for believing that considerable quantities of the carbides of iron have been formed within the earth and that these carbides have in some instances reacted with water to produce the magnetic oxide of iron, Fe_3O_4, and those hydrocarbons found in petroleums. The constant deflection of the magnetic needle, as noted in the locality of certain petroleum deposits, has given support to the theory of the formation of these petroleums from carbides of iron. The organic theories account for the formation of petroleum from animal or vegetable matter enclosed in sedimentary deposits which have afterwards been converted into rock. These theories may be divided into two classes: (1) Those which consider petroleums to be the product of direct decomposition or reaction of the organic matter within the formation in which it is enclosed, and (2) those which consider petroleums as distillates produced by natural causes from the enclosed organic matter. The latter is perhaps the most plausible of any single theory and may be made to explain the many variations of petroleums obtained from different localities. The vegetable matter be-

lieved to have been responsible for the formation of petroleums is known as diatoms, a minute form of plant life. Forminifera are believed to be the minute animal organisms responsible for other petroleums. With regard to the latter it is well known that a wax-like material, cholesterol, is present in all fatty animal bodies and that, when this material is destructively distilled, certain portions of the distillate are optically active (see Art. 4, ISOMERISM). From certain petroleums distillates are obtained which for similar ranges of boiling point exhibit the same optical activity as do the distillates from cholesterol. This is considered as satisfactory evidence that such petroleums have been produced from animal matter. Both animal and vegetable matter, if subjected to distillation under high pressure, can be made to yield hydrocarbon mixtures similar to those found in petroleums. In nature it is probable that distillation was conducted in the presence of steam at the lowest possible temperature and at gradually increasing but comparatively high pressures as the overlying deposits accumulated upon those formations inclosing the organic matter being distilled. The natural conditions of temperature, pressure and time cannot be duplicated in the laboratory or factory by man, and as they are most important factors in so far as the characteristics of the ultimate products are concerned, the differences between natural and artificial bitumens are readily explained. As an example may be cited the destructive distillation of organic matter under atmospheric pressure which produces distillates known as tars and which are chemically quite distinct from distillates produced from the same materials under pressure, owing to the formation of hydrocarbons of entirely different series. In nature secondary distillations might also take place which would result in a complete change in the characteristics of the first material formed. If the secondary distillation was fractional, a solid residue might remain and thus an asphalt or rock asphalt be produced. The secondary distillate would then appear as a petroleum of quite different characteristics from the one first formed.

14. Production of Petroleums

World's Production of Crude Petroleum. Statistical information relative to the production of crude petroleum dates back to 1857, with Roumania producing 1977 bbl. In 1859 the United States started with a production of 2000 bbl, about one-half as much as was produced by Roumania during the same year. Since then the production of crude petroleum has increased with wonderful rapidity until it has become the largest and one of the most important natural industries of the world. In 1860 the United States assumed the lead of the oil producing countries, which lead it has steadily maintained. Since 1903 it has annually produced more than all of the other countries combined. At the close of 1913 its total recorded production was somewhat over three billion barrels, while that of the whole world was over five billion barrels. In 1913 its nearest competitor, Russia, produced less than one-fourth as much. The world's production by countries from 1904 to 1913, according to Day (16a), is given in Table I. As of particular interest in connection with the production of bituminous materials for highway engineering should be noted the remarkable growth in the crude petroleum industry of Mexico. Starting with the production of some 200 000 bbl in 1904, it ranked next to the last of the twelve important petroleum producing countries. By 1913 it was producing over 25 000 000 bbl and ranked third among the

important petroleum producing countries. Since 1912 Mexican petroleum has been extensively used in the manufacture of bituminous road and paving materials in the United States and promises to become a most important source of supply for European countries. Another petroleum of interest from the standpoint of highway engineering in the United States is that obtained from Trinidad, which in 1911 produced about 180 000 bbl; in 1912, 451 986 bbl; and in 1913, 503 616 bbl.

Table I.—World's Production of Crude Petroleum 1904–1913, in Barrels of 42 Gallons

Country	1904	1905	1906	1907	1908
United States	117 080 960	134 717 580	126 493 936	166 095 335	178 527 355
Russia	78 536 655	54 960 270	58 897 311	61 850 734	62 186 447
Mexico	220 653	320 379	1 097 264	1 717 690	3 481 610
Roumania	3 599 026	4 420 987	6 378 184	8 118 207	8 252 157
Dutch East Indies	6 508 485	7 849 896	8 180 657	9 982 597	10 283 357
Galicia	5 947 383	5 765 317	5 467 967	8 455 841	12 612 295
India	3 385 468	4 137 098	4 015 803	4 344 162	5 047 038
Japan	1 419 473	1 472 804	1 710 768	2 001 838	2 070 145
Peru	345 834	447 880	536 294	756 226	1 011 180
Germany	637 431	560 963	578 610	756 631	1 009 278
Canada	552 575	634 095	569 753	788 872	527 987
Italy	25 476	44 027	58 577	59 875	50 966
Other Countries*	40 000	30 000	30 000	30 000	30 000
Entire World	218 299 419	215 361 296	214 010 124	264 958 008	285 089 315

Country	1909	1910	1911	1912	1913
United States	183 170 874	209 557 248	220 449 391	222 935 044	248 446 230
Russia	65 970 350	70 336 574	66 183 691	68 019 208	60 935 482
Mexico	2 448 742	3 332 807	14 051 643	16 558 215	25 696 291
Roumania	9 327 278	9 723 806	11 107 450	12 976 232	13 554 768
Dutch East Indies	11 041 852	11 030 620	12 172 949	10 845 624	11 966 857
Galicia	14 932 799	12 673 688	10 519 270	8 535 174	7 818 130
India	6 676 517	6 137 990	6 451 203	7 116 672	*7 500 000
Japan	1 889 563	1 930 661	1 658 903	1 671 405	1 942 009
Peru	1 316 118	1 330 105	1 368 274	1 751 143	1 857 355
Germany	1 018 837	1 032 522	1 017 045	1 031 050	* 995 764
Canada	420 755	315 895	291 096	243 336	228 080
Italy	42 388	50 830	74 709	53 778	50 334
Other Countries*	30 000	30 000	200 000	470 000	517 516
Entire World	298 226 073	327 482 746	345 545 624	352 210 881	381 508 916

* Estimated.

Production and Importation of Petroleum in the United States. According to location and classification the oil producing areas of the United States are commonly divided into seven fields, known as (1) the Appalachian Field, (2) the Lima-Indiana or Ohio-Indiana Field, (3) The Illinois Field, (4) the Mid-Continent Field, (5) the Gulf Field, (6) the California Field and (7) the Colorado-Wyoming Field. Relatively small quantities of petroleum have also been exploited in Missouri, Michigan, Utah, Arkansas, Montana, Washington, Oregon, Idaho, Nevada, New Mexico and Alaska. The Appalachian Field extends from western New York in a

general southwesterly direction along the western side of the Alleghany Mountains, thru Pennsylvania, eastern Ohio, the northwestern part of West Virginia into eastern Kentucky and Tennessee. The Lima-Indiana Field includes the northwestern part of Ohio and middle Indiana; the Illinois Field, Illinois and northwestern Kentucky; the Mid-Continent Field, southeastern Kansas, eastern Oklahoma and northern Texas; and the Gulf Field, Louisiana and all but the northern portion of Texas. Other fields of direct interest to the United States are the Mexican and Trinidad Fields. The former covers an area embraced in the coastal plain extending along the Gulf of Mexico from the Panuco River in Tamaulipas to below Tuxpan. The latter is located on the Island of Trinidad some miles from the great lake asphalt deposits. The California, Gulf, Illinois, Mid-Continent, Mexican and Trinidad Fields produce petroleums extensively used in the manufacture of bituminous road and paving materials. The production by fields and importation of petroleum by the United States from 1904 to 1913, according to Day (16a), is given in Table II. It will be noted that the production of the Appalachian Field has quite steadily declined during the 10 years covered by Table II, and that there has been a rapid decline in that of the Lima-Indiana Field. As neither of these fields produce petroleums well adapted to the manufacture of bituminous road and paving materials, their decline is of no direct interest

Table II.—Production and Importation of Crude Petroleum by the United States, 1904–1913, in Barrels of 42 Gallons

Field	1904	1905	1906	1907	1908
Appalachian	31 408 567	29 366 960	27 741 472	25 342 137	24 945 517
Lima-Indiana	24 689 184	22 294 171	17 554 661	13 121 094	10 032 305
Illinois	....	181 084	4 397 050	24 281 973	33 686 238
Mid-Continent	6 186 629	12 585 777	22 838 553	46 846 267	48 323 810
Gulf	24 631 269	36 526 323	20 527 520	16 410 299	16 272 074
California	29 649 434	33 427 473	33 098 598	39 748 375	44 854 737
Colorado-Wyoming	....	....	....	....	....
Other Fields	*a*515 877	*a*385 792	*a*336 082	*a*345 190	*a*412 674
Imported by U. S.	....	....	....	....	....
Total	117 080 960	134 717 580	126 493 936	166 095 335	178 527 355

Field	1909	1910	1911	1912	1913
Appalachian	26 535 844	26 892 579	23 749 832	26 338 516	25 921 785
Lima-Indiana	8 211 443	7 253 861	6 231 164	*c*4 925 906	4 773 138
Illinois	30 898 339	33 143 362	31 317 038	28 601 308	23 893 889
Mid-Continent	50 833 740	59 217 582	66 596 477	65 478 345	84 920 225
Gulf	10 886 240	9 680 465	10 999 873	8 545 018	8 542 494
California	55 471 601	73 010 560	81 134 391	*d*87 272 593	97 788 525
Colorado-Wyoming	*b*336 667	*b*358 839	*b*421 616	1 778 358	2 595 321
Other Fields	....	....	....	....	*e*10 843
Imported by U. S.	69 614	557 181	1 709 932	7 383 229	17 869 082
Total	183 240 488	210 114 429	222 159 323	230 318 273	266 815 312

a Includes Colorado and Wyoming.
b Includes Michigan and Missouri.
c Includes Michigan.
d Includes Alaska.
e Includes Alaska, Michigan, Missouri, and New Mexico.

in highway engineering. These petroleums, however, for many years supplied most of the demand for light distillates such as gasoline. As the demand for these distillates has increased out of proportion to the production of high gasoline bearing petroleums, many of those suitable for the manufacture of bituminous road and paving materials have been subjected to cracking processes which make them unsuitable for such use but has greatly increased the yield of light distillates. The production of California petroleums, most of which are eminently suited for the manufacture of bituminous road and paving materials, has shown a tremendous increase until in 1910 it exceeded that of Russia, the second petroleum producing country of the world. This immense increase together with the importation of large quantities of Mexican petroleum has much more than offset the marked decline in production of the Gulf Field and gradual later decline of the Illinois Field. The Mid-Continent Field, which is of some importance from the standpoint of highway engineering, has shown an increase second only to that of California. The importation of petroleum by the United States assumed considerable proportions in 1911 when over 1 700 000 bbl, almost entirely of Mexican production, were imported and used extensively in the manufacture of road and paving materials. By 1913 this importation had increased to over 17 000 000 bbl and the Mexican petroleum refining industry had become firmly established in the eastern part of the United States. During 1912 and 1913 appreciable quantities of Trinidad petroleum were imported by the United States. At the close of 1914 it was estimated that over 18 500 000 bbl of petroleum had been imported during that year, most of it coming from the Mexican Field. The estimated total production of petroleum in the United States during 1914 was 284 000 000 bbl, an increase of some 36 000 000 bbl over that of 1913.

The Mining of Petroleum. Petroleum is obtained from the porous reservoir rock in which it occurs (see Art. 13, FORMATION OF PETROLEUMS) by boring thru the overlying strata until the oil bearing rock is struck. These borings are made in much the same manner as the driving of artesian wells. In petroleum fields, the oil bearing stratum is usually struck at depths varying from 50 to 2000 ft. According to the anticlinal theory of petroleum formation, the porous stratum also contains water and may contain natural gas. As the gas, oil and water will have accumulated at different levels by force of gravity, it is necessary to locate that level at which the petroleum has collected (see Fig. 1). Once oil is found in such structural formation it is evident that a great number of borings into the same oil bearing strata will follow certain general lines. The occurrence of petroleum along these general lines was noted long before the anticlinal theory was evolved and operations were extended at both extremes of direction indicated by the general lines connecting those borings or wells which had proved most prolific. At the present time the services of trained

Fig. 1. Anticlinal Oil Bearing Stratum

geologists are employed in locating new sources of supply as their knowledge of geological formations and the probable trend and extent of oil bearing strata when once struck reduces to a science the former hit-and-miss methods of petroleum prospecting. Fig. 1 further illustrates the possible simultaneous production of gas and petroleum or petroleum and water from a single well. As the petroleum may occur under pressure, it may be driven to the surface with great force after the oil rock has been struck. Such wells are called gushers. In many cases they flow for only a few days, after which pumping becomes necessary. Certain gushers, however, flow for a long time and produce enormous quantities of oil. A possible production of as high as 200 000 bbl per day has been reported from some phenomenal gushers. The annual capacity of a single Mexican well has been estimated at 30 000 000 bbl. As the large gushers produce oil more rapidly than it can be handled, recourse is had to a process known as capping by means of which, after oil has been struck, the boring may be closed and the outflow of oil regulated by a valve. Before capping devices were perfected immense quantities of petroleum were not only lost but caused ruination to the vegetation of the localities in which the large gushers were struck. Sometimes the oil caught fire at the mouth of the well. In such a case it could not be extinguished until large quantities had been consumed in flame and the flow had greatly subsided. In many cases, after a well stops flowing and pumping proves no longer economical, an increased yield may be obtained by what is known as shooting the well. The shooting process is conducted by exploding a shell or torpedo, containing nitroglycerin, which has been lowered to the bottom of the well. The well is then said to have been torpedoed. This results in fracturing the oil bearing stratum and facilitating the flow of oil to the bottom of the boring. Frequently the flow of oil from the well is again started by this means and may continue for some time, after which pumping becomes necessary. The well may be torpedoed a number of times with good results before it is finally abandoned. Sometimes a well driven into a more favorbly located portion of the oil bearing stratum will drain oil from another well and cause it to stop producing.

Transportation and Storage of Crude Petroleum. Crude petroleum is usually transported by pipe lines and tank steamers. The pipe lines vary from 4 to 8 in in diameter and some of them are exceedingly long. They are placed well underground. Pumping stations are located at varying intervals and the oil is pumped from station to station. When the crude oil is very viscous recourse is sometimes had to a pipe rifled in much the same manner as a gun barrel. In such cases a small quantity of water is pumped with the oil and, owing to the centrifugal motion imparted by the rifling, finds its way to the inner surface of the pipe and serves as a lubricant between it and the oil. In the United States many different grades and types of petroleums are piped to the large refineries thru the same line, and the grades therefore often become mixed. The longest known line extends for a distance of 1600 miles from the Oklahoma Field northward thru Chicago and from thence to the Atlantic Coast. A refinery located at Bayonne, N. J., may therefore refine petroleum from a number of fields. When cheap water transportation can be had the crude petroleum is often piped directly to tank barges or tank steamers. In some cases where harborage is unsatisfactory the pipes are laid under water to the point at which ships may be anchored. At the Tuxpan station, Mexico, ships are loaded in the open roadstead, the oil being pumped thru submarine

pipe lines. These are connected with the ships by flexible tubing. The advantage of this method is that ships of any draught may be loaded to full capacity. Tank steamers vary somewhat in size and design but are generally divided into tanks or compartments in order that the ship may not become unbalanced when listing in a rough sea. The principal dimensions of a modern tank steamer designed to carry 2 250 000 gal of oil in bulk are as follows: Length over all 435 ft, beam 54 ft, depth 31 ft, 6 in. Such a steamer is subdivided into 16 tanks for oil. Petroleum refineries are usually so located that they may either be directly connected by pipe lines with the source of supply or else delivery from tank steamers may be made direct. At the refinery the crude oil is run into large vertical cylindrical storage tanks constructed of sheet metal and usually holding from 30 000 to 75 000 bbl. They are set rather far apart and are surrounded by an earth pit or ditch of sufficient capacity to hold the entire contents of the tank in case of leakage or fire. The greatest danger from fire is encountered from lightning during electrical storms. The pit is designed to prevent the spread of fire in such cases to other parts of the refinery by streams of burning oil. In the storage tanks sedimentation takes place (see Art. 9) and most of the water and mineral matter, if present, separates and settles to the bottom of the tank. The petroleum is piped directly from the storage tank to the topping plant or still for refining. When the contour of the site of the plant makes it practicable, the storage tanks may be set at a higher elevation than the rest of the refinery so that the oil may be run by gravity directly from the tanks to the stills.

15. Classification of Petroleums

General Characteristics. Petroleums are mixtures or solutions of a great number of hydrocarbons and often contain sulphur, nitrogen and oxygen derivatives of the hydrocarbons. In general the composition of all petroleums is similar but the relative proportions of the individual constituents vary to such an extent that wide variations occur in both the physical and chemical properties of petroleums from different sources. Upon ultimate analysis, the elemental constituents are found to occur within comparatively narrow limits for all types and grades so that the elemental composition does not serve as a practical method of classification. In general, carbon is found to lie between 80 and 87%; hydrogen 10–14%, sulphur 0–5%, nitrogen 0–2%, and oxygen 0–4%. The specific gravity of petroleum varies from 0.73 to 1.00 and slightly higher. The viscosity generally increases with the specific gravity. Petroleums vary in color from greenish brown to nearly black and often exhibit a reddish brown or orange color by transmitted light. They are sometimes slightly fluorescent. Those of lighter gravity are usually fluid, oily liquids, while the heavier petroleums are thick, viscous and often sticky. As a rule they have a rather unpleasant odor, particularly those which carry a high percentage of sulphur. They carry varying quantities of light volatile hydrocarbons which vaporize upon exposure and leave the oil more viscous, and with a somewhat higher gravity if it is subject to prolonged storage in the open. Their flash point may also be raised by this means. Many of them flash at ordinary temperature, particularly those of lighter gravity. When freed from the natural impurities such as water and sediment, petroleums are completely soluble in carbon disulphide and carbon tetrachloride, and to a large extent soluble in light gravity paraffin naphtha. As their gravity

increases, however, they become less soluble in the latter solvent. They are practically insoluble in dimethyl sulphate. When passed thru a column of fuller's earth, a fractionation of the constituents occurs and the coloring matter is removed to a great extent. This is due to what is known as selective absorption of the mineral colloidal matter, which exhibits a decided preference for the heavier black asphaltic hydrocarbons present. The first liquid percolating thru the fuller's earth is nearly water white and of very much lighter gravity than the original. Natural filtration thru clays and other colloidal matter is believed to be responsible for the formation of naphtha springs, a few of which are known to exist. The principle of selective colloidal absorption is made use of in certain refining operations to which some petroleum products are subjected. Petroleums are themselves often powerful solvents or fluxes for the asphalts and other solid native bitumens. Their solvent action in this connection increases with their gravity and usually with a decrease in their percentage of light volatile hydrocarbons. Their coefficient of expansion generally varies inversely with their specific gravity and lies between 0.0006 and 0.0009 per °C. Their specific heat also varies inversely with their specific gravity and lies between 0.4 and 0.5. There are a number of methods of classifying petroleums, the most widely used being according to locality or fields, as most of the oils from a given locality resemble each other in physical and chemical properties more closely than do those from different fields. Locality classification has to some extent been used to indicate grades, and thus the term Pennsylvania Grade has been used to cover all petroleums which exhibit properties very similar to those found in Pennsylvania, altho they may not occur in that state. Petroleums are also sometimes classified and sold according to specific gravity, particularly when oils of different gravity occur in the same field. The Baumé scale is made use of by petroleum producers and refiners in preference to direct specific gravity expressions (see Art. 33). It is therefore customary to hear a petroleum spoken of as a 38° B oil or 14° B oil, etc. The petroleums of North America in particular are often classified according to the character and quantity of semisolid residue which may be obtained by subjecting them to fractional distillation, the terms used to designate such residues or bases being paraffin, asphaltic and semiasphaltic.

Paraffin Petroleums are those in which the paraffin or C_nH_{2n+2} hydrocarbons predominate in both the fluid and solid compounds present. They are usually of low gravity and low flash point and upon fractional distillation yield large quantities of valuable light distillates, lubricating distillates and scale paraffin. The semisolid residues are soft, greasy bodies which contain a relatively small amount of the cyclic C_nH_{2n}, C_nH_{2n-2}, C_nH_{2n-4}, etc, hydrocarbons so prevalent in asphalts. They are chemically stable because of the high percentage of paraffins present. They are commercially the most valuable of any of the types of petroleums but are unsuited for the manufacture of bituminous road and paving materials except dust palliatives and fluxes, as they have practically no cementitious qualities. In the early days of the sheet asphalt paving industry, they were extensively employed in the manufacture of fluxes for refined asphalts but since the production of asphaltic and semiasphaltic petroleums has increased so enormously their use in this connection has fallen off. Petroleums from the Appalachian, Lima-Indiana Fields and some from the Mid-Continent Field are classed as paraffin petroleums. Those from the Appalachian represent the purest paraffin type and are the most valuable,

selling in certain instances as high as $2.50 per bbl at the well during 1914. A diagram of the relative proportion of constituents in a crude paraffin petroleum is shown in Fig. 2. This diagram represents a typical paraffin petroleum fractionally distilled down to semisolid consistency, the residue amounting to 8% being represented by the area below the line *a a*. The white area A represents the paraffins and naphthenes; area B, the more stable unsaturated cyclic compounds; area C, the unstable hydrocarbons usually having an unsaturated side chain; and area D, the solid asphaltic hydrocarbons. The entire area above *a a* is considered as representing the total mixed fractions which have been distilled off. The relative percentage of the various classes of hydrocarbons in the total distillate as well as in the semisolid residue is indicated by the shaded areas. If this were done for individual fractions it would be found that all but about 2% of the first 10% fraction consists of paraffin and naphthenes, the remainder being unsaturated but stable cyclic hydrocarbons. The absence of asphaltic hydrocarbons D would be shown by practically nothing being removed when treated with fuller's earth. Failure of ordinary concentrated sulphuric acid to act upon the distillate would prove the absence of olefines and similar unsaturated hydrocarbons C. The amount removed by the action of fuming sulphuric acid would be indicated by B, and A would be those hydrocarbons unattacked by the fuming sulphuric acid. It will be noted that about 48% of the semisolid residue consists of paraffins and naphthenes and only about 2% of asphaltic hydrocarbons.

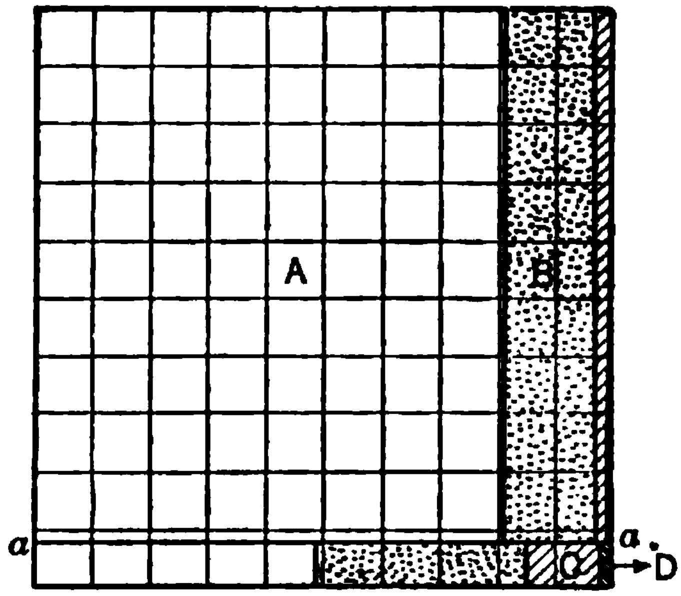


Fig. 2. Crude Paraffin Petroleum.

Asphaltic Petroleums are those in which the cyclic hydrocarbons of the C_nH_{2n}, C_nH_{2n-2}, C_nH_{2n-4} and similar series predominate in both the fluid and solid compounds present. They are usually of high gravity and upon volatilization or fractional distillation produce large percentages of semisolid and solid residues closely resembling the native asphalts in physical and chemical properties. These residues are more unstable than those obtained from paraffin petroleums but are highly cementitious, while the latter are not. The solid hydrocarbons of the C_nH_{2n+2} series are either wholly lacking in these residues or are present in very small amounts. The asphaltic petroleums yield but little light volatile distillates and the heavier distillates are often inferior for commerical purposes unless most carefully produced by vacuum or steam distillation. They are the least valuable commercially of any type of petroleum and during 1914 sold for as low as $0.38 per bbl at the well. They are, however, eminently suited to the manufacture of bituminous road and paving materials and are extensively used for this purpose. Most petroleums from the California, Mexican and Trinidad Fields may be classed as asphaltic, altho Mexican petroleums are sometimes classed as semiasphaltic. Most of the truly asphaltic petroleums occur in the United States or immediate vicinity and the use of such oils in the manufacture of bituminous road and paving materials has naturally developed in the United States to a greater extent than in any other country. For

many years their use in highway engineering was confined to the Pacific Coast where those manufactured from California petroleums were readily available. Later discovery of other petroleums which were suitable for this purpose rapidly developed the industry to one of the most important in connection with the utilization of petroleum. The relative proportion of constituents in a heavy crude asphaltic petroleum is shown in Fig. 3. The lettered areas in this diagram represent the same series of hydrocarbon constituents as described for paraffin petroleums under Fig. 2. It will be noted that the asphaltic petroleum shows a very much higher percentage of semisolid residue obtainable by fractional distillation than does the paraffin type. Moreover, the area D in this residuum has increased to about 33% against 2% for the paraffin petroleum. The paraffin and naphthene hydrocarbons A have completely disappeared in the residue, and areas B and C show a notable increase. This residue is highly cementitious and is in fact an asphalt very similar in physical and chemical properties to the bitumen of the native asphalts. In the distillates paraffin and naphthene hydrocarbons are present to a less extent than in the distillates from the paraffin petroleum. In this connection, however, it should be noted that while area A in Fig. 2 is composed mainly of paraffin hydrocarbons, area A in Fig. 3 is composed mainly of naphthene hydrocarbons. Area C has increased considerably, indicating a lower degree of chemical stability, but it is not proportionately as great as that shown in Fig. 5, which illustrates the effect of a cracking distillation upon both distillates and residue of a semiasphaltic petroleum.

Fig. 3. Crude Asphaltic Petroleum

Semiasphaltic Petroleums are those which hold an intermediate position between the paraffin and asphaltic petroleums. The distillates obtained by fractional distillation more nearly resemble those from paraffin petroleums but the cyclic hydrocarbons predominate and the naphthenes or C_nH_{2n} series largely replace the C_nH_{2n+2} series. Between given boiling points therefore the distillates from semiasphaltic petroleums have a higher specific gravity than do those from paraffin petroleums. A greater percentage of semisolid residue may be obtained from them but not usually as much as from asphaltic petroleums. These residues are very much like those obtained from asphaltic petroleums but a small quantity of the solid C_nH_{2n+2} or paraffin hydrocarbons are present. They are chemically less stable than those from paraffin petroleums but somewhat more stable than the purely asphaltic residues. Many semiasphaltic petroleums are well suited to the manufacture of bituminous road and paving materials, but, as they yield valuable distillates, they are not always primarily refined for the residues which they will yield. By means of cracking processes the yield of distillates may be increased, and this is sometimes accomplished at the expense of the quality of residue produced owing to the formation of olefines or other series of hydrocarbons containing an unsaturated open chain or side chain. When refined primarily for residues the oxidation or blowing process is often resorted to after a certain amount of preliminary distilla-

tion, as by this means the percentage of residue may be greatly increased. If the initial distillation is not carried far enough, however, semisolid residues are produced which are decidedly lacking in cementitiousness and are therefore unsatisfactory as road or paving materials. Petroleums from the Gulf, Illinois and many from the Mid-Continent and Colorado-Wyoming Fields are classed as semiasphaltic. Mexican petroleums are sometimes placed in this class because of the fact that solid paraffin hydrocarbons are found in their residues. They are peculiar, however, in the fact that they yield as high a percentage of semisolid residues and in many cases higher than do the asphaltic petroleums. The relative proportion of constituents in a typical semiasphaltic petroleum is shown in Fig. 4, while changes produced by cracking such petroleum during distillation are shown in Fig. 5.

a

Fig. 4. Crude Semiasphaltic Petroleum

Fig. 5. Semiasphaltic Petroleum, Cracked

As compared with Fig. 3, it will be noted that the area below *a a* in Fig. 4 shows approximately the same proportion of heavy asphaltic hydrocarbons D altho the area itself is considerably smaller. The proportion of other highly unsaturated hydrocarbons C is less, indicating greater chemical stability. In Fig. 5 the total area below *a a* has materially decreased owing to the increase in distillates caused by the cracking process. As compared with Fig. 4, the relative proportion of area C has been increased in both distillates and residue while the proportions of all of the other areas in the residue have decreased owing to the fact that these hydrocarbons have been broken up into distillates and the unsaturated hydrocarbons included in area C. This is particularly noticeable in regard to area B. It should be noted, however, that many of the hydrocarbons still remaining in area D have been altered chemically and are much more unstable than those in area D of Fig. 4. In this article no attempt has been made to cover the refining of petroleums, as both the methods of refining and the refined products are given under Arts. 19 to 22 inc.

NATIVE ASPHALTS

16. Origin of Native Asphalts

Occurrence of Native Asphalts. Native asphalts are semisolid or solid native bitumens which for all practical purposes may be considered as the natural residuums of semiasphaltic or asphaltic petroleums. They are

widely distributed over the earth, and history records a knowledge of their occurrence and use prior to petroleum. They are known to have been used in 2000 B.C. as a cementing material in construction of brick work in the city of Babylon. They were used for a similar purpose by the Incas of South America long before the discovery of the Americas by the white race. Evidence has also been presented of their use in highway construction by these people. They are mainly found at or near the surface of the earth, altho in certain instances they are obtained in an almost pure state from veins or seams in rock formations where they occur in much the same manner as coal. Those at or near the surface of the earth usually contain appreciable quantities of non-bituminous impurities such as water, vegetable matter and mineral matter. It is almost impossible to remove all of these impurities by refining processes so that, unless originally occurring in a pure state, the refined native asphalts do not contain as high a percentage of bitumen as do refined petroleums. Where the asphalt occurs impregnating a porous reservoir rock the entire deposit is called rock asphalt. In such cases the percentage of mineral matter is greatly in excess of the pure asphalt (see Arts. 23 and 24). When they occur at the surface of the earth as a seepage into a natural basin they are commonly known as lake asphalts. The lake asphalts are more widely known and are obtained in greater quantities than any other form of native asphalt. Their use in highway engineering in the United States preceded by many years the use of manufactured residues from semiasphaltic and asphaltic petroleums. Being themselves natural petroleum residues, their origin is identical with that of petroleum (see Art. 13).

Formation of Native Asphalts. Native asphalts are largely composed of a mixture of those hydrocarbons which originally occurred in the heavier and less volatile portions of the particular petroleums which were immediately responsible for their formation. The relative proportion and character of the original petroleum hydrocarbons may, however, have been considerably modified by peculiar conditions attending the natural processes to which they were subjected during the actual production of asphalt. These conditions were not necessarily the same as those employed in the manufacture of semisolid and solid residues from petroleums, and the native asphalts therefore often differ in certain characteristics from the manufactured petroleum asphalts. Where native asphalts are direct products of secondary distillation, they most commonly occur impregnating the original porous reservoir rock or as rock asphalts. Owing to the absence of water in the rock formation or to natural fissures in the otherwise impervious overlying strata, they may have been forced under natural pressure and at temperatures sufficiently high to have made them more or less mobile into large rock crevices where they solidified into hard mineral vein deposits. Depending upon the characteristics of the original petroleum and the temperatures and pressures to which they were subjected, the consistency of the asphalt may vary from a soft and viscous semisolid to a hard, brittle black body. A distillation under pressure might not bring them to semisolid consistency when cold but by seepage to the earth's surface and later evaporation of the more volatile hydrocarbons they might in time become solid. If subjected to high natural temperatures during formation, they might become hard and brittle. If the temperature was excessive, the hydrocarbons might be so altered that the material would be converted into one that would not melt upon the application of heat, in which case it would not be true asphalt. Such solid form of bitu-

men is most commonly known under the name of GRAHAMITE. If at high temperatures the material underwent further alteration and became insoluble in carbon disulphide, it would be known as an asphaltic coal or pyrobitumen. Should a semisolid or solid native residue be produced from a paraffin petroleum without material alteration of the paraffin hydrocarbons to cyclic or bridge compounds, these residues would more nearly resemble in chemical and physical characteristics the manufactured solid paraffin and would not be termed asphalts. Such mineral substances as OZOCERITE and HATCHETTITE belong to this class and are of no direct interest in highway engineering.

17. Production of Native Asphalts

Main Sources of Supply of Native Asphalts. Statistics relative to the world's production of native asphalts are not so complete as those for petroleum. Most statisticians include under the general heading asphalts all types of semisolid and solid native bitumens as well as rock asphalts and certain pyrobitumens. The rock asphalts in particular represent a very considerable tonnage, the importance of which from the standpoint of highway engineering is apt to be misjudged if the fact is lost sight of that most of this tonnage is represented by the rock itself and not by the asphalt which impregnates it. Trinidad and Venezuela are by far the largest producers of asphalt proper, altho the latter country shows a lower

Table III.—Production of Crude Native Asphalts and Other Semisolid and Solid Native Bituminous Materials, 1904–1913, in Tons

Country	1904	1905	1906	1907	1908
Trinidad *b* (British West Indies)	152 393	114 845	150 373	171 271	143 552
Venezuela *a*	14 910	38 808	22 128	37 637	31 539
United States	64 167	62 898	78 052	85 913	78 565
Italy *c*	123 347	117 929	144 802	178 127	148 433
France	250 222	211 043	216 405	195 136	188 616
Germany	101 121	113 513	129 388	139 567	98 088
Spain	4 146	7 135	8 587	9 057	13 635
Austria-Hungary	4 029	8 257	10 633	11 385	12 239
Russia	*d* 95	23 659	12 517	14 116	24 961

Country	1909	1910	1911	1912	1913
Trinidad (British West Indies)	159 416	157 120	*a*179 718	*a*189 496	*a*230 031
Venezuela	37 292	31 890	50 163	65 875	83 825
United States	99 061	98 893	87 074	95 166	92 604
Italy	123 361	179 261	207 926	181 946	....
France	186 298	187 085	....	....	....
Germany	85 446	89 491	90 256	....	....
Spain	5 822	7 072	9 700	....	....
Austria-Hungary	11 179	9 070	....	....	....
Russia	*e*........	*e*........	....	....	....

a Exports.
b Includes small quantity of manjak produced in Barbados.
c About 7% represents asphalt; remainder is bituminous sandstone and limestone.
d Ozocerite only; quantity of asphalt not available.
e Not available.

tonnage than do the United States, Germany, France and Italy, whose production consists very largely of rock asphalt. The production of these materials by the largest producing countries of the world from 1904 to 1913, according to Day (16b), is given in Table III. In this connection it is of interest to note that altho asphalts have their direct origin in petroleum, the largest petroleum producing countries are not the largest producers of native asphalts. This is due to the fact that in general those formations best adapted to the collection of petroleum in paying quantities do not encourage the resultant change to asphalt or other semisolid or solid forms of bitumen.

Production and Importation of Asphalts in the United States. Semisolid and solid native bituminous materials occur in various parts of the United States. The principal producing States are Utah, California, Oklahoma, Kentucky, Texas and West Virginia. Utah produces most of the pure solid bitumens known as gilsonite, impsonite and grahamite, also the pyrobitumen wurtzilite. Some gilsonite occurs in Colorado, and grahamite is also obtained from Oklahoma and West Virginia. In 1913 California produced only bituminous sandstone. The same is true for Kentucky. Oklahoma and Texas produce both bituminous sandstone and bituminous limestone. The production by States, according to Day, (16b), from 1909 to 1913, is given in Table IV. In addition it should be noted that in 1914 a considerable deposit of solid native bitumen was discovered in the Philippines on the Island of Leyte.

Table IV.—Production of Crude Native Semisolid and Solid Bituminous Materials by States, 1909–1913, in Tons

State	1909	1910	1911	1912	1913
Utah	28 919	35 697	30 846	32 514	30 810
California	43 825	41 299	36 481	36 741	27 870
Kentucky	15 898	9 938	*a*	*b*10 145	*b*17 465
Oklahoma	*c*10 419	11 959	*d*19 747	15 766	16 459
Total	99 061	98 893	87 074	95 166	92 604

a Included in Oklahoma.
b Includes Texas.
c Includes West Virginia and Texas.
d Includes Kentucky.

Table V.—Most Important Production and Importation of Semisolid and Solid Bituminous Materials by the United States, 1909–1913, in Tons

Material	1909	1910	1911	1912	1913
Gilsonite and grahamite in U. S.	42 783	33 087	35 236	*a*39 930	*a*35 055
Maltha in U. S.	652	1 252	8 574	474	*b*
Bituminous rock in U. S.	55 376	64 554	42 654	54 762	*c*57 549
Asphalt from Trinidad	111 416	118 472	111 630	103 711	125 273
Asphalt from Venezuela	34 191	37 523	38 196	60 393	87 609
Total imported bituminous rock *d*	6 409	3 696	8 180	3 976	6 395
Oil asphalt in U. S.	129 594	161 187	277 192	354 344	436 586

a Includes wurtzilite.
b Included in bituminous rock.
c Includes maltha.
d Bituminous limestone.

The production and importation from 1909 to 1913 by the United States of native semisolid and solid bituminous materials of particular interest in highway engineering are given in Table V. For the sake of comparison the production of oil asphalts in the United States during that period is also given. From Table V it will be noted that in general the total annual production of native semisolid and solid bituminous materials has remained quite constant, the largest tonnage of actual bitumen being represented by the products known as GILSONITE and GRAHAMITE. The importation of rock asphalt has remained so low as to be of very minor importance. This is not due to lack of desirable qualities in the foreign bituminous rock but to the impracticability of its competition with native rock asphalts and the purer form of bitumen upon which transportation charges are much lower. A very large tonnage of asphalt has annually been imported from Trinidad and Bermudez, most of which has found its use in highway engineering. In 1909 this importation exceeded the production of asphalt from petroleum. The manufacture of asphalt from petroleum, however, has increased so rapidly that in 1913 it more than doubled the total importation for that year. In this connection it is of interest to note that in 1913 the importation of petroleum suitable for manufacturing asphalt was sufficient to have produced over three times the amount of oil asphalt manufactured during that year had it all been refined for that purpose. This importation was almost entirely from Mexico.

The Mining of Asphalts. Asphalts are mined in a number of ways, according to the method of occurrence and degree of hardness of the crude material. Rock asphalts are quarried in much the same manner as any rock deposit. The purer forms of solid bitumen occurring in veins of fissures below the surface of the earth are obtained as is coal by sinking a shaft to the vein formation and then removing the asphalt in lumps by means of picks. The lumps upon being elevated to the surface are sometimes sorted into a number of grades, depending upon the presence or absence of included mineral matter. GILSONITE and GRAHAMITE are thus mined and may often be obtained in a practically pure state, being free from water and mineral matter. The crude lake asphalts, such as TRINIDAD and BERMUDEZ, which are less hard, still possess sufficient solidity to make possible their removal by means of hand-pick or mattox. They are flaked up by this means and the fragments are loaded by hand upon carts or small cars which transport them to the refinery or vessels which are to carry them to the refinery. The excavations thus made gradually fill up owing to an almost imperceptible flow of the mass which seeks a constant level. Where conditions are suitable, a crane with a bucket of the clam-shell type may be used for the purpose of excavation and loading, the weight of the bucket being sufficient to cause it to sink into the mass of asphalt. Bermudez asphalt has been mined in this manner.

Transportation and Storage of Crude Asphalts. The harder varieties of crude solid bituminous materials, such as GILSONITE and GRAHAMITE, are transported from the mines by rail and usually in open cars. The lumps retain their shape under normal conditions and may, therefore, be transported and handled like so much coal. They are often of sufficient purity to require no refining other than that which will modify their consistency to that suitable to the use for which they are to serve. Lake asphalts on the other hand require refining in order to remove impurities. The lake asphalts used in the United States are transported in the crude condition to

that country, where they are refined. They are carried in vessels so constructed that practically the entire hold may be filled with the lumps of crude material, which gradually coalesce to a solid mass during transportation. This makes it necessary to again mine the material from the vessel upon its arrival at the refinery. Here it is again picked out or removed by a clam-shell bucket, and if it cannot be immediately refined and barreled, it is unloaded into an artificial pit or lake for storage, where it again coalesces. A third mining operation is then required before it eventually reaches the refining tank. Owing to its extreme viscosity and tendency to froth at elevated temperatures, it cannot be transported by pipes when heated to a molten state. At ordinary air temperatures it exhibits a strong tendency to adhere to the sides of transporting containers and for this reason the insides of such containers are usually clayed in order to facilitate removal. The cost of handling crude lake asphalt is considerably higher than for any other type of crude bituminous material, and this materially influences the market value of the refined product as compared with asphalts manufactured from petroleum.

18. Types of Native Asphalts

Classification of Asphalts. While the semisolid and solid native bituminous materials may be classified in much the same manner as petroleums under the headings paraffin and asphaltic, the asphalts themselves are usually classified by certain characteristics peculiar to a given source of supply. This is not invariably true, however, as such products as gilsonite and grahamite are obtained from a number of different localities. The individual crude asphalts of particular interest in highway engineering are treated in the following paragraphs under names by which they are commonly known to the trade. Rock asphalts or bituminous rock are not here included as they are treated under a separate subdivision. Refined asphalts are dealt with in another subdivision (see Arts. 19 to 22 inc).

Trinidad Asphalt is the best known and most extensively used of any of the native asphalts. It occurs in enormous quantities on the Island of Trinidad, which lies off the north coast of South America, being separated from the mainland of Venezuela by a narrow channel on the south and the Gulf of Paria on the west. It occurs in two forms, known as lake pitch and land pitch, which differ somewhat in properties but originate from the same source. The lake pitch or main deposit occupies what is thought to be the crater of an extinct mud volcano, while the land pitch occurs in layers which were produced by overflows from the lake. The pitch lake has an area of about 127 acres and is of unknown depth. Borings have been made to a depth of 135 ft at the center, with no indication of having reached the bottom of the deposit. The estimated minimum available tonnage of asphalt in this lake is over 9 000 000 tons.

Crude Lake Asphalt is a uniform, cheesy mixture of gas, water, fine sand, clay and bitumen, carrying about 39% of the latter constituent. It is sufficiently solid to bear the weight of men and vehicles but flows slowly and excavations made in the lake gradually fill up. After refining the bitumen carries a high percentage of sulphur containing hydrocarbons, some nitrogen but little or no oxygen. In common with other native asphalts, no solid paraffins are present but saturated cyclic hydrocarbons of the C_nH_{2n-2} series have been found. These saturated hydrocarbons amount to about 25% of the total bitumen. Polycyclic polymethylenes

similar to those contained in asphaltic petroleums are present in that portion of the bitumen which is soluble in paraffin naphtha, and extremely complex unsaturated hydrocarbons make up the bulk of the naphtha insoluble material. The crude lake asphalt is refined in order to remove the water and gas. Most of the mineral matter, however, is in such a finely divided state that it persistently remains in suspension and but little of it separates by sedimentation under the agitation to which it is necessary to subject the molten asphalt during refining in order to prevent injury by local overheating. The relative proportion of constituents in both the crude and refined lake asphalt is quite constant. They are shown in the following diagrams. It will be noticed that the refined asphalt contains about 7% of what is classed as organic matter not soluble in carbon disulphide. While it is commonly reported thus, Richardson has shown that in reality it consists mainly of water of hydration of the clay which is present, inorganic material which is volatile at the high temperature necessary to produce ash, together with about 0.3% of bitumen which is persistently retained by the fine mineral matter and cannot be removed with the solvent carbon disulphide which is used to determine the percentage of bitumen.

Fig. 6. Crude Trinidad Lake Asphalt Fig. 7. Refined Trinidad Lake Asphalt

The refined asphalt may, therefore, be considered as roughly containing 57% bitumen and 43% mineral matter. Upon ignition it yields a characteristic flesh pink ash. The high percentage of mineral matter largely limits its use to certain of the more expensive types of pavement because of the fact that in the cheaper types it cannot successfully compete in price with the purer asphalts which contain practically 100% bitumen. It has been claimed that the mineral matter in Trinidad asphalt is so uniformly distributed thruout the bitumen and exists in such a finely divided state that it makes a better filler for sheet-asphalt aggregates than will other types of pure mineral matter which have to be added for that purpose (see Sect. 17).

Crude Land Asphalt occurs in a variety of forms, depending upon its age since overflowing from the lake and also upon the natural conditions to which it has been subjected since such overflow. Different varieties are known as cheese pitch, iron pitch, cokey pitch, etc. As some of it has been coked by forest fires, and therefore injured for industrial purposes, it has to be selected with some care. It is invariably harder both in the

crude and refined state than the lake asphalt, and in general requires about half again as much flux to bring it to a given consistency or penetration. Its specific gravity is somewhat higher than the lake asphalt as it contains about 2% more mineral matter and a correspondingly lower percentage of bitumen. Nearly all of the land asphalt exported from Trinidad goes to the United States but it constitutes only a small proportion of the total. The total exportation of both types from 1909 to 1913, as given by Day (16b), is shown in Table VI. From this table it will be seen that the United States consumes considerably more than half of the total exportation.

Trinidad asphalt was first used in pavement construction in the United

Table VI.—Exportation of Asphalt from Trinidad, 1909–1913, in Tons

Country	Type	1909	1910	1911	1912	1913
To United States........	Lake	97 629	109 198	103 590	95 111	123 873
	Land	13 787	9 274	8 040	8 600	1 400
To Europe.............	Lake	49 345	65 778	67 105	85 299	104 153
	Land	224	150	....	....	....
To Other Countries......	Lake	....	....	983	486	605
	Land	....	....	....	....	....

States at Newark, N. J., in 1870. Its use on local roads in Trinidad antedates 1836.

Bermudez Asphalt, second only to Trinidad asphalt in the extent of its production and use, occurs as a shallow lake deposit in the State of Sucre in Venezuela, about 30 miles from the coast and almost due west of the Island of Trinidad. The pitch lake covers about 1000 acres of swampy country and is not readily accessible. It has been formed by the overflow of soft pitch or heavy maltha from a number of springs. Upon exposure the maltha liberates gas and gradually hardens. The lake varies in depth from about 2 to 9 ft. It is covered in many places by a rank vegetable growth which by catching fire from time to time has hastened the hardening of the asphalt. When mined it is quite solid for a depth of about 2 ft, but is softer than Trinidad asphalt. The fresh maltha as it exudes from the springs is practically pure bitumen, but the asphalt as mined carries appreciable quantities of extraneous matter. It is not of uniform composition in the crude state as it contains varying quantities of water, vegetable matter and mineral matter. In general the water varies from 10 to 50%, and over; vegetable matter from 1 to 6%; mineral matter from 1 to 3%; and bitumen from 45 to 88%. The refined Bermudez asphalt is much softer than refined Trinidad asphalt but carries a higher percentage of bitumen, usually 94 to 95%. The bitumen varies, however, from 92 to 97%. The vegetable matter or organic material insoluble in carbon disulphide usually lies between 1.5 and 5%, and the mineral matter or ash runs from 1.5 to 2.5%. When heated, refined Bermudez asphalt has a characteristic odor quite different from the Trinidad product. Upon ignition it yields a brownish pink ash. The vegetable matter consists of very small fragments of twigs, veins of leaves, etc, which are not

readily removed by refining. Nearly all of the Bermudez asphalt exported from Venezuela finds its way to the United States, where it is refined, fluxed and used quite extensively in highway engineering in the construction of sheet asphalt and other types of bituminous pavements. The pure bitumen of Bermudez asphalt is similar in character to that of Trinidad asphalt and carries about the same percentage of sulphur hydrocarbons. It has, however, a greater percentage of volatile hydrocarbons.

Maracaibo Asphalt is another Venezuelan product found in the State of Zulia, almost due west of the Bermudez lake. It is produced as an exudation from a maltha spring and resembles the Bermudez asphalt in many respects, altho it has a characteristic odor which readily distinguishes it from the Bermudez product. It has been used to a limited extent in the construction of sheet-asphalt pavements in the United States but is not an important source of supply from the standpoint of highway engineering in general.

Cuban Asphalts. A number of deposits of asphalt are located on the Island of Cuba and some have been worked to a limited extent. Those products which have been utilized in highway engineering to any extent are, in the crude state, hard, brittle asphalts. They carry about 75% bitumen, over 20% mineral matter, and 3 or 4% organic matter insoluble in carbon disulphide. In general appearance these Cuban asphalts resemble refined Trinidad asphalt but require a greater amount of flux to produce an asphalt cement of given consistency. Upon ignition they yield a brownish ash which is different from the Trinidad ash.

Gilsonite is a hard, brittle, lustrous material which occurs in various localities. The most important commercial deposits are, however, found in the State of Utah. It is found in rock crevices or veins from which it is picked out or mined like coal. It is ordinarily quite free from impurities and usually consists of over 99.5% bitumen. It therefore yields but little ash upon ignition. Its specific gravity generally lies between 1.04 and 1.05, altho some grades which contain more than the average amount of mineral matter may show a slightly higher gravity. Its fracture is lustrous and conchoidal. It consists of about 95% of unsaturated hydrocarbons, most of them probably being polycyclic and bridge compounds of complex structure. It melts at from 149° to 163° C (300° to 325° F) and at 205° to 218° C (400° to 425° F) may be fluxed with petroleum residuums to form asphalt cements. It has been quite extensively used in combination with blown petroleum residuums to produce rubbery, non-ductile asphalt cements sometimes known as mineral rubber. It is one of the most expensive of the crude native bituminous materials and its commercial competition with others used in highway engineering is usually limited to fluxed compounds of which it constitutes a comparatively small percentage. It is sold in two grades, firsts and seconds; the former consisting of large lumps free from powder, and the latter of smaller and more powdery fragments. As it is almost pure bitumen it does not have to be refined prior to its use in the manufacture of materials of direct interest to the trade. It is employed to a considerable extent in the manufacture of japans, paints, varnishes, electric insulations and acid-proofing materials.

Grahamite is more widely distributed in nature than gilsonite, which it resembles in hardness and brittleness. It usually occurs as vein or crevice deposits and it is mined in much the same manner as gilsonite. Oklahoma is the principal producing state. Like gilsonite, native grahamite is almost pure bitumen and does not have to be refined prior to its use in the manu-

facture of finished products. It may, however, contain as high as 5 or 6% of mineral matter. Its specific gravity is somewhat higher than gilsonite and usually lies between 1.10 and 1.20. Its fracture is irregular or hackly. It has been used to some extent in the manufacture of asphalt cements for use in highway engineering. Owing to its hardness a large amount of flux is usually required to soften it to a desirable consistency. Upon being heated it does not really melt but swells up and intumesces. In this respect it resembles the pyrobitumens. It has probably been produced in nature at comparatively high temperatures. It consists almost entirely of complex, unsaturated hydrocarbons which are practically insoluble in light paraffin naphthas. Its uses are similar to those described for gilsonite.

OTHER ASPHALTS of less importance from the standpoint of highway engineering than those above described occur in various parts of the world. Among those which have been used to a limited extent may be mentioned deposits occurring in California and Mexico, known respectively as California and Mexican asphalts. Most of the California asphalts are vein deposits of varying degrees of purity, the working of which has been largely abandoned because of their inability to commercially compete with the asphalts manufactured from California petroleums. The Mexican asphalts are principally hardened maltha effusions which occur in the vicinity of Tampico, Tuxpan and Chapapote. These deposits have not been worked to any great extent and only very limited quantities have found their way into the United States for use in the paving industry. Two other asphalts which may be mentioned are GLANCE PITCH and MANJAK. The former is widely distributed over the world but occurs principally in East Syria and Egypt. The latter is found on the island of Barbados. Both of these products are almost pure bitumens which are hard and brittle. They resemble gilsonite and grahamite in many respects. They are not used in highway engineering and their chemical and physical properties are therefore not given in the following subsection on refined petroleum and asphalt products.

REFINED PETROLEUM AND ASPHALT PRODUCTS

19. Distillation of Petroleums

Petroleum Stills. Stills for refining petroleums vary greatly in size and somewhat in construction. The refining stills most commonly used in the United States are cylindrical in form and are set horizontally in a brick framework. Another type which has in the past been used to some extent is known as the cheese-box still. It has very much the shape of a large round cheese and is set directly over the furnace, all but the bottom being exposed to the outside air. The bottom is double-curved to admit of expansion and offers a large heating surface. The modern type of petroleum still used in the manufacture of road and paving materials consists of a cylindrical steel shell set horizontally in brickwork so that the lower half is entirely concealed except at the ends. The upper half is exposed to the air except for a thin sheet metal covering. Three or four stills are usually set side by side to form a battery and are separated merely by brick partitions. They are placed in the open without covering of any sort. The large stills have a charging capacity of 1000 or 1200 bbl. They are approximately 40 ft in length and 15 ft in diameter, and are fitted with a metal dome at the top which connects with the vapor line leading to the condensers. The condenser coils consist of a number of parallel lines of pipes connecting headers which are set at successively lower elevations in a large cooling tank filled with running water. By this means more efficient cooling surface is obtained than by a single coil. The condenser discharges thru a running line which is provided with a trap for separating any uncondensed gases which may accompany the distillate. The running line con-

nects with a look-box provided with a glass door so that the stream of distillate may be watched and sampled from time to time. The outlet from the look-box leads to a manifold which connects with a number of storage tanks. The distillate may be run into any one of these storage tanks by closing all of the valves leading from the manifold but the one which will admit the distillate into the line leading to that particular tank. The look-box and manifold are located under cover in what is known as the tail-house. Fig. 8 shows a diagram of a plant such as has been described. The still is fitted with lugs which rest on roller bearings set in the brick framework in order that the expansion at high temperatures may be cared for without injury to the setting. It has three manholes, one at the top and one at each end near the bottom in order to facilitate cleaning and

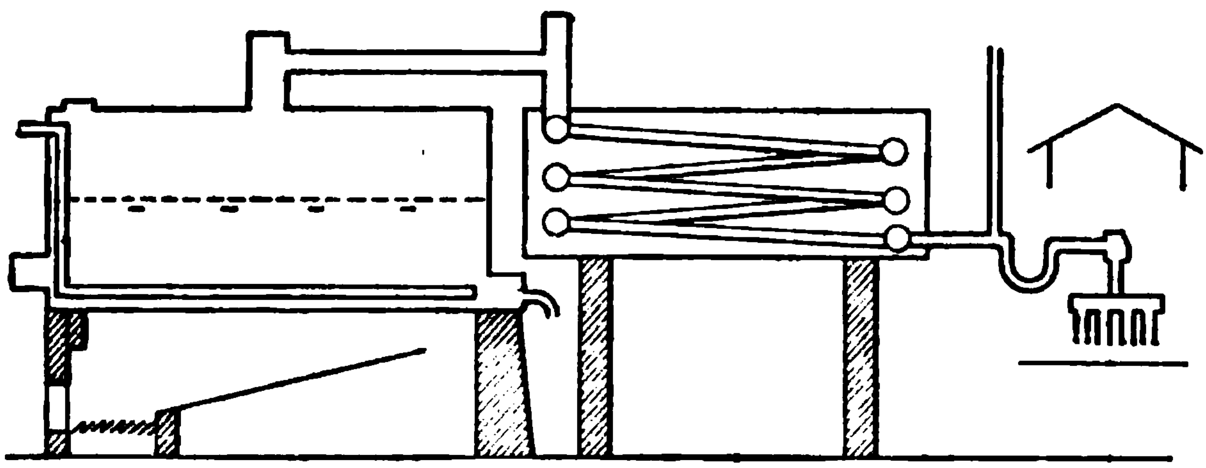


Fig. 8. Petroleum Distillation Plant

repairs. The petroleum is charged into the still thru a filling pipe from the top. One or more steam pipes are placed lengthwise in the still near the bottom. The steam pipe is fitted with spider jets deflected downward so that the oil in contact with the hottest portion of the still may be thoroly agitated during distillation, if desired, by the injection of dry steam. Metal sockets are so placed that thermometers or pyrometers may be inserted in the oil in the still and the vapor in the dome. A discharge pipe leads from near the bottom of one end of the still and connects with storage tanks or barrelling kettles by a number of branch pipes which are steam-jacketed. These tanks or kettles are usually equipped with steam coils so that their contents may always be kept sufficiently fluid to handle properly. When they are to be filled with very highly heated material from the still, they are sometimes first charged with live steam in order to prevent the hot residual from catching fire by spontaneous combustion and causing an explosion. They may also be equipped with trap doors to relieve the pressure should an explosion occur. The storage tanks or barrelling kettles are usually large enough to hold the residual contents of at least four or five stills. At any time during distillation samples of the residual petroleum may be drawn off thru a small pipe located near the bottom of the still and often tapped into the discharge pipe close to the still and between it and the main discharge valve. At the end of the distillation the discharge valve is opened and the residual material either pumped or blown by live steam into the proper storage tank or barrelling kettle. Sometimes a number of stills in a battery are set at different levels so that the residue from the first may be run by gravity into the second and so on thruout the battery. Such an arrangement is used in what is known as the continuous method of distillation. In this system, which is used to a considerable

extent in Russia, a constant flow of oil is run thru the battery of stills and the resdue is continuously discharged from the last. The single still or batch method, as most commonly employed in the United States when primarily used in the manufacture of road and paving materials, is in general conducted as follows:

Petroleum Refining. After most of the impurities have been separated by sedimentation in the storage tank, the crude petroleum may either be charged directly into the refining still or it may first be run thru a topping plant in which all of the remaining water and some of the very light oils are removed (see Art. 9). The latter is to be preferred because of the extreme care with which preliminary distillation must be conducted, even when a small quantity of water is present in the more viscous petroleums, in order to prevent foaming. Such foaming, if not carefully controlled, may result in passing most of the charge thru the vapor line and condensers. After charging, the contents of the still are slowly heated until the distillate emerges from the condenser. The gravity of the running distillate is taken from time to time by a man stationed in the tail-house. Depending upon just what distillate products are to be manufactured, cuts are made at the proper gravity by deflecting the flow to another storage tank. Owing to the tendency of asphaltic petroleums to crack during distillation (see Art. 10) as soon as the vapor temperature is sufficiently high to prevent condensation within the still, live steam is forced thru the steam pipe. The distillate then becomes a mixture of oil and water which, however, readily separates by gravity. Samples of the residual material remaining in the still are also taken from time to time and tested for consistency and other properties which are to be secured. When the proper consistency has been obtained, the distillation is stopped and the residual discharged into the cooler, storage tank or barrelling tank. After acquiring experience with any particular type of oil, the manufacturer is able to gage with considerable accuracy what characteristics are possessed by the residual, from the quantity and gravity of the distillate that has been removed. Very frequent sampling of the residual is not therefore always necessary. As some of the tests for consistency require an hour or more to make, it is evident that if distillation is continued while the test is being made, the residual will have changed appreciably during that period. Exact control is therefore largely a matter of experience and knowledge of what the results of a given test indicate as regards the residual in the still at the

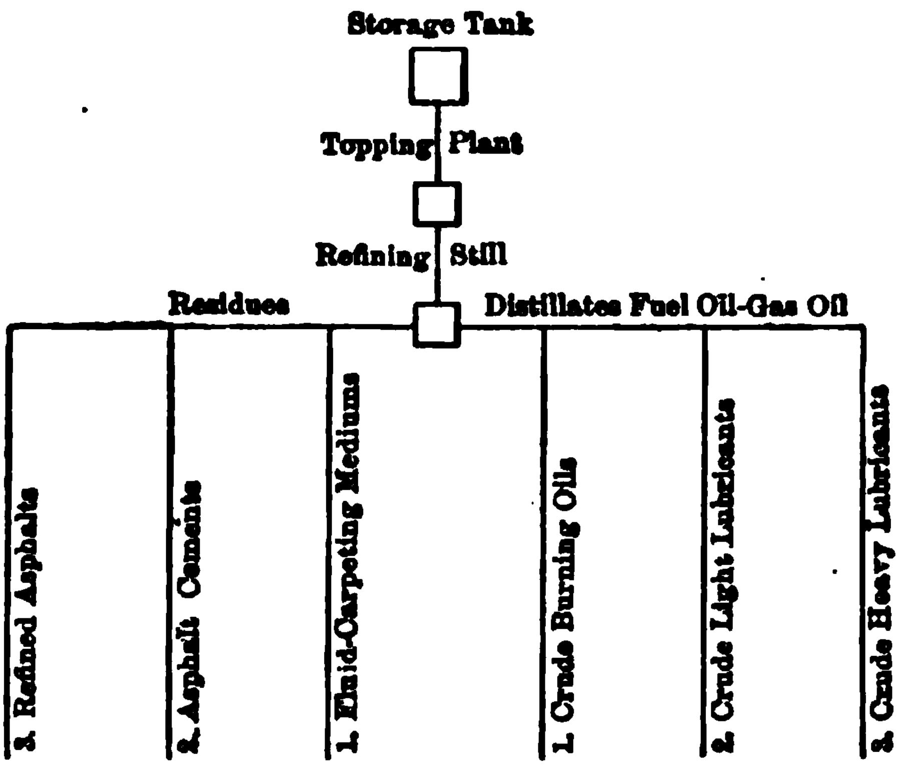


Fig. 9. Distillation of Asphaltic Petroleum

expiration of the test. Sometimes distillation is inadvertently carried beyond the proper point for the production of a given product. In such case the residual may sometimes be utilized by running it into the cooler and there mixing with it the residue from another distillation which has not been carried quite far enough. Various modifications in a given method of distillation are necessary to produce the various products which may be required. Fig. 9, however, serves to illustrate in general, the practice followed in the manufacture of straight residuals for use in highway engineering, and their accompanying distillates, from a crude asphaltic petroleum. As the quantity of distillate removed from a given charge of petroleum increases, the residual remaining in the still becomes more and more viscous until finally it will solidify upon cooling. In most cases the residual is a finished product after it has been discharged from the still, and requires no further treatment. Distillates, however, are usually further refined by redistillation in a smaller still and subsequent agitation with concentrated sulphuric acid, followed by washing with a solution of caustic soda and finally with water. The sulphuric acid combines with and polymerizes the unsaturated compounds which are present and forms a sludge acid which separates by gravity from the purified distillate. The sludge acid may then be treated for the recovery of the sulphuric acid, leaving behind the hydrocarbons which have been removed from the distillate. When the distillates are of inferior quality for the manufacture of refined products or when market conditions do not warrant their further refining, they are sometimes run into a common tank after the lightest fraction has been separated, and are sold as fuel oil distillate. Refined distillates are sold under the names of gasoline, kerosene, burning oils, turpentine substitutes, spindle oils, cylinder oils, dust layers, etc. The residues of various consistency are sold as dust layers, carpeting mediums, fluxes, asphalt cements and refined asphalts. For further details and principles governing distillation in general, see Art. 10.

Distillate Dust Layers are usually heavy non-volatile distillates which may have been treated with sufficient sulphuric acid to remove all objectionable odor, due to the presence of hydrocarbon derivatives containing sulphur. They are usually transparent or semitransparent and vary in color from pale yellow to dark brownish red. They resemble and are, in effect, inferior lubricating oils which flow readily at ordinary temperature and do not possess or develop after application any true cementitiousness. Their function is to lay dust in much the same manner as water but, being non-volatile, their effect is more permanent than water. They should be used sparingly or otherwise there is danger of disintegration of the road surface thru the medium of their lubricating action. As a rule they are sufficiently fluid to apply to a road surface by means of an ordinary street sprinkler, but a pressure distributor is to be preferred for this purpose in order to secure a very light, uniform distribution. Their consistency is determined by means of a viscosimeter, the test being ordinarily made at 25° C (77° F). The physical and chemical characteristics of a typical distillate dust layer are as follows:

Distillate Dust Layer

Specific gravity 25°/25° C (77°/77° F)	0.892
Specific viscosity (Engler) 50 cu cm, 25° C (77° F)	3.4
Flash point (closed cup)	105° C (221° F)
Burning point (closed cup)	158° C (316° F)
Loss at 163° C (325° F), 5 hr, 50 g	12.6%
Character of residue	Fluid

Soluble in carbon disulphide (total bitumen)	100.00%
Organic matter insoluble	0.00%
Inorganic matter insoluble (ash)	0.00%
	100.00%
Bitumen insoluble in 86° B naphtha	0.00%
Bitumen insoluble in carbon tetrachloride	0.00%
Fixed carbon	0.40%

All distillate dust layers are completely soluble in carbon disulphide, 86° B naphtha and carbon tetrachloride. They seldom, if ever, exceed 0.920 specific gravity or 12.0 specific viscosity. Their flash point, burning point and loss by volatilization vary considerably, the first two properties increasing and the last decreasing with the specific gravity. The residue from the volatilization test is invariably fluid and greasy. They yield a low percentage of fixed carbon, seldom over 1.0%, and upon ignition should be free from ash. Their physical and chemical properties change but little after application, and their value as dust layers lasts only so long as they are not supersaturated with dust particles. If used in excessive quantities they produce an oily, muddy emulsion in wet weather, as they do not serve as waterproofing agents.

Crude and Residual Dust Layers. In some cases crude petroleums are sold and used directly as dust layers. As a rule, however, the manufacturer or producer prefers to remove some of the lighter and more valuable distillates. This may be done either by running the oil thru a topping plant or subjecting it to fractional distillation. The former practice is common with the viscous asphaltic crude oils while the more fluid semi-asphaltic oils are subjected to distillation. For cold application the character of a topped oil is not materially different from the original crude altho its specific gravity, specific viscosity, flash point and burning point are slightly increased and its loss by volatilization decreased. Some crude oils are too viscous to be used directly as dust layers, in which case either the original crude or the topped crude may be thinned down to suitable viscosity by adding the proper quantity of some cheap petroleum distillate, such as a distillate dust layer or burning oil fraction. These materials vary greatly in character according to the crude oil from which they are produced and their method of manufacture which is difficult to determine exactly by ordinary routine tests. Their function is similar to that of the distillate dust layers altho they prove effective for a longer period, owing to the fact that they form a thin superficial coat upon the surface treated. They should be sufficiently fluid to apply cold by means of a pressure distributor at a rate of not over ⅙ gal per sq yd. Altho they often contain appreciable amounts of the heavier asphaltic hydrocarbons and upon prolonged exposure in thin films may develop some adhesiveness, they do not harden after application with sufficient rapidity to be used in the construction of bituminous carpets. If used in excessive quantities they either act as lubricants or product a greasy black mud in wet weather. They are brownish black in color and most of them resemble crude petroleum in general appearance. The following analyses are typical of crude and residual petroleums which have been marketed for cold surface application.

Crude Heavy Asphaltic Petroleum

Specific gravity 25°/25° C (77°/77° F)	0.962
Specific viscosity (Engler) 50 cu cm, 25° C (77° F)	139.5
Flash point (closed cup)	45° C (113° F)
Burning point (closed cup)	67° C (153° F)
Loss at 163° C (325° F), 5 hr, 50 g	24.8%
Character of residue	Viscous fluid

Soluble in carbon disulphide (total bitumen)	99.80%
Organic matter insoluble	0.15%
Inorganic matter insoluble (ash)	0.05%
	100.00%

Bitumen insoluble in 86° B naphtha	10.62%
Bitumen insoluble in carbon tetrachloride	0.00%
Fixed carbon	5.10%

Topped Medium Asphaltic Petroleum

Specific gravity 25°/25° C (77°/77° F)	0.938
Specific viscosity (Engler) 50 cu cm, 25° C (77° F)	56.2
Flash point (closed cup)	130° C (266° F)
Burning point (closed cup)	145° C (293° F)
Loss at 163° C (325° F), 5 hr, 50 g	26.8%
Character of residue	Viscous fluid

Soluble in carbon disulphide (total bitumen)	99.91%
Organic matter insoluble	0.05%
Inorganic matter insoluble (ash)	0.04%
	100.00%

Bitumen insoluble in 86° B naphtha	12.90%
Bitumen insoluble in carbon tetrachloride	0.00%
Fixed carbon	6.40%

Most of the crude and residual petroleums sold as dust layers have a specific gravity of between 0.930 and 0.980. Their specific viscosities at 25° C (77° F) in general vary from about 25 to 140. Many of them are too viscous for successful cold application. Upon being subjected to the volatilization test at 163° C (325° F) for 5 hr they usually lose from 8 to 30% and the residues thus produced are usually fluid. They seldom yield over 7% fixed carbon but may show as high as 15 or 18% of bitumen insoluble in 86° B naphtha. Those produced from light semiasphaltic petroleums may show 2% or less of naphtha insoluble bitumen. They are almost entirely soluble in carbon disulphide and also in carbon tetrachloride.

Residual Fluxes are fluid petroleum residuums preferably carrying a minimum amount of volatile material. They are used primarily for the purpose of softening refined asphalts, especially the native asphalts which are too hard to be directly available for use in highway engineering. Those produced from paraffin petroleums usually have a specific gravity of from 0.920 to 0.940. The gravities of the semiasphaltic fluxes lie between 0.940 and 0.975, while the asphaltic fluxes run from 0.975 to 1.01 and over. In general their flash point should be well above 163° C (325° F) as this is the temperature to which they are likely to be heated when being combined with the solid asphalts. They should not lose over 5% by weight when subjected to the volatilization test for 5 hr at 163° C (325° F). The residues from this test may or may not harden appreciably but the degree of hardening should never cause the asphalt cement in which they are incorporated to show a loss of over 50% in penetration when subjected to the volatilization test at 163° C (325° F). In this respect they differ from the most desirable type of residual carpeting medium. The characteristics of certain typical residual fluxes available in 1914, as given by Forrest (20c), are shown in Table VII. In general, as fluxes increase in specific gravity, they must

Table VII.—Residual Fluxes

Specific gravity 15.5° C (60° F)	0.931	0.961	1.01
Baumé gravity	20.4°	15.7°	heavy
Flash point	205° C (401° F)	268° C (514° F)	166° C (331° F)
Loss at 163° C (325° F) 5 hr, 50 g	0.62%	0.14%	2.22%
Residue, float test at 65° C (149° F)	Too soft	20 sec	60 sec
Soluble in carbon disulphide (total bitumen)	99.80%	99.50%	99.80%
Paraffin scale	4.42%	2.96%	0.65%
Sulphur	0.63%	0.43%	3.33%

be used in greater quantity with a given refined asphalt to produce an asphalt cement of given penetration. The asphaltic fluxes usually show a higher loss by the volatilization test than do the paraffin and semiasphaltic fluxes. This is due to the fact that in their manufacture distillation cannot be carried to as high a temperature because the asphaltic residual would become too hard for use as a flux if distilled to the same temperature as the paraffin and semiasphaltic petroleums. This is also shown by the relatively low flash point of most asphaltic fluxes.

Residual Carpeting Mediums are products not unlike certain of the very heavy residual fluxes. They are too viscous to apply cold but when heated should be sufficiently fluid to be capable of uniform distribution over a road surface at the rate of not over ½ gal per sq yd if applied by means of a pressure distributor. They should either possess considerable cementitiousness or develop after application sufficient cementitiousness to properly perform their function, which is that of adhering to the road surface and holding in place the covering of fine aggregate with which they combine to form a bituminous carpet. Those which harden appreciably when subjected to the volatilization test are to be preferred. Many of the residual petroleums used as carpeting mediums are entirely unsuited for the purpose because they are too fluid to possess the requisite degree of cementitiousness, and during manufacture have been distilled at such high temperature that all chance of loss by volatilization, to a sufficient extent to cause appreciable hardening after application, has been eliminated. On the other hand, if they originally possess sufficient consistency or stability to serve adequately as bituminous cements for the mineral aggregate of the carpet, it is often difficult, if not impossible, to distribute them uniformly, and at the proper rate, over the road surface. Soft asphalt cements fluxed to proper consistency with a volatile distillate possess certain advantages over the straight residual carpeting mediums, especially for use on broken stone and gravel roadways. The characteristics of residual petroleums which have been used as carpeting mediums are shown in Table VIII. For the reasons above mentioned, No. 1 is unsuitable for use in this connection, while No. 2, altho showing reasonably satisfactory physical and chemical characteristics, is more difficult to apply properly.

Asphalt Cements from Petroleum produced by straight distillation vary in characteristics according to the type of petroleum distilled and the purpose for which the asphalt cement is prepared. Those intended for use in bituminous macadam construction are usually softer than for use in bituminous concrete or sheet asphalt pavements. In general the finer the mineral aggregate which is to be cemented, the lower should be the penetration of the asphalt cement. This is due to the fact that fine aggregates

Table VIII.—Residual Carpeting Mediums

	(1)	(2)
Specific gravity 25°/25° C (77°/77° F)	1.010	1.001
Float test at 50° C (122° F)	viscous fluid	60 sec
Flash point (closed cup)	196° C (385° F)	173° C (343° F)
Loss 163° C, (325° F) 5 hr, 50 g	2.50	3.75
Residue, float test at 50° C (122° F)	Too soft	96 sec
Soluble in carbon disulphide (total bitumen)	99.91%	99.86%
Organic matter insoluble	0.06%	0.07%
Inorganic matter insoluble (ash)	0.05%	0.07%
	100.00%	100.00%
Bitumen insoluble in 86° B naphtha	19.72%	13.66%
Bitumen insoluble in carbon tetrachloride	0.00%	0.00%
Fixed carbon	11.50%	7.00%

have less inherent mechanical stability in a pavement than coarse aggregates and therefore require a more solid and harder cement to hold the mineral particles in place. The most desirable penetration for asphalt cements for a given type of pavement varies with the type of oil from which they are produced. The penetration test is the principal control test used in their manufacture and as the penetration or consistency varies, so also will the other physical and chemical properties. These variations differ somewhat, however, for asphalts produced from different types of petroleum and are often greatly modified by variations in the method of distillation. Table IX illustrates the general scope and character of these variations, as applied to asphalt cements of different penetrations produced by straight distillation of the same crude petroleum. The actual test values are not typical of all asphalt cements of the same penetration produced from different petroleums and should not be so interpreted. Considering the first three analyses it will be noticed that as the penetration at 25° C (77° F) decreases, the specific gravity, flash point, melting point, naphtha insoluble bitumen, and fixed carbon gradually increase. The ductility, loss by volatilization and penetration of residue, on the other hand, decrease. The solubility in carbon disulphide and carbon tetrachloride, however, remain about the same. The fourth analysis represents an asphalt cement which has been badly injured by cracking during the distillation process. While its penetration at 25° C (77° F) is the same as that shown by No. 3, its penetration at 4° C (39° F) is very much lower, showing extreme susceptibility to temperature changes. Its melting point has decreased somewhat and also its ductility. It shows a notable increase in loss by volatilization at 163° C (325° F) and under this test produces a very hard residue, as shown by the low penetration. Cracking is directly shown by the presence of nearly 2% of organic material insoluble in carbon disulphide and also by the high percentage of its bitumen which is insoluble in carbon tetrachloride. If examined under the microscope the organic material insoluble in carbon disulphide would be found to resemble soot and to be, in fact, amorphous carbon produced by decomposition of some of the heavy hydrocarbons of the original petroleum. The percentage of bitumen insoluble in 86° B naphtha has notably increased as has also the percentage

Table IX.—Asphalt Cements Produced by Straight Distillation

	(1)	(2)	(3)	(4)
Specific gravity	1.030	1.040	1.045	1.050
Flash point	220° C (428° F)	240° C (464° F)	250° C (482° F)	200° C (392° F)
Penetration 25° C (77° F)	125	90	55	55
Penetration 4° C (39° F)	....	45	20	5
Penetration 46° C (115° F)	....	....	250	....
Melting point	40° C (104° F)	50° C (122° F)	57° C (135° F)	50° C (122° F)
Ductility 25° C (77° F) cm	100+	100+	60	20
Loss 163° C (325° F) 5 hr, 50 g	2.0 %	1.0 %	0.3 %	5.0 %
Penetration residue 25° C (77° F)	90	60	35	5
Soluble in CS_2 (total bitumen)	99.90%	99.88%	99.85%	98.00%
Organic matter insoluble	0.05%	0.06%	0.07%	1.92%
Inorganic matter insoluble	0.05%	0.06%	0.08%	0.08%
	100.00%	100.00%	100.00%	100.00%
Bitumen insol. 86° B naphtha	23.0 %	26.0 %	28.0 %	32.0 %
Bitumen insol. CCl_4	0.0 %	0.0 %	0.0 %	3.5 %
Fixed carbon	13.0 %	15.0 %	16.0 %	20.0 %

of fixed carbon. All asphalt cements which have been injured by cracking do not exhibit such marked changes as shown above. The exact changes are largely dependent upon the extent of cracking and original character of the petroleum distilled. The preliminary stages of cracking are sometimes indicated by only one or two tests in the interpretation of which care must be taken to first identify the original petroleum. As a means of general comparison the relative characteristics of typical asphalt cements of approximately the same penetration produced by distillation of Texas, California, and Mexican petroleums are shown in Table X.

Table X.—Asphalt Cements from Various Petroleums

Petroleum	Texas	California	Mexican
Specific gravity 25°/25° C (77°/77° F)	1.020	1.035	1.047
Flash point	205° C+ (401° F+)	205° C+ (401° F+)	205° C+ (401° F+)
Penetration at 25° C (77° F)	95	85	90
Penetration at 4° C (39° F)	43	18	30
Melting point	56° C (133° F)	48° C (118° F)	55° C (131° F)
Ductility 25° C (77° F) cm	40	100+	80
Loss 163° C (325° F) 5 hr, 50 g	0.4 %	1.0 %	0.3 %
Penetration of residue at 25° C (77° F)	70	45	60
Soluble in CS_2 (total bitumen)	99.85%	99.92%	99.88%
Organic matter insoluble	0.08%	0.04%	0.10%
Inorganic matter insoluble (ash)	0.07%	0.04%	0.02%
	100.00%	100.00%	100.00%
Bitumen insoluble 86° B naphtha	24.80%	21.30%	28.80%
Bitumen insoluble in CCl_4	0.07%	0.02%	0.08%
Fixed carbon	13.00%	11.80%	15.60%
Paraffin scale	1.00%	0.00%	1.60%
Sulphur	0.75%	1.19%	4.95%

Refined Asphalts from Petroleum are similar in character to asphalt cements produced by distillation of the same petroleum. The term refined asphalt, or R.A., usually implies that the material is too hard to be used in highway construction without first fluxing it with a residual flux to softer consistency or higher penetration. Refined asphalts may, therefore, be considered as very hard asphalt cements. If carefully prepared they differ only from the softer asphalt cements in those properties which have been shown to change by a gradual increase or decrease as the result of continued distillation. Their penetration at 25° C (77° F) is usually 40 or less. They may be softened to any desired penetration by combining with them the proper proportion of suitable flux. They are mainly used in connection with the construction of sheet asphalt pavements where it is desired to control and to modify, at the paving plant, the consistency of the asphalt cement which is used. This practice has been handed down from the days when only refined native asphalts were used to any extent in sheet asphalt construction. Since then, however, many municipalities have learned what penetration of various asphalt cements is most desirable to meet their local conditions of climate, traffic, aggregate, etc, and as the manufacturers can meet penetration requirements within very close limits, there is a general tendency to purchase ready prepared asphalt cements rather than to purchase separately and afterward combine the refined asphalt and flux. There is much to be said for the old practice where careful control at the paving plant is assured, but the ready prepared asphalt cements have found favor in the smaller types of plants, particularly in connection with bituminous concrete construction, where a coarse aggregate is used. Ready prepared asphalt cements are, moreover, almost invariably used in bituminous macadam construction.

Sludge Asphalts are sometimes produced as by-products in the purification of petroleum distillates. These distillates are agitated with concentrated sulphuric acid in lead-lined agitators. The sulphuric acid combines with and produces certain hydrocarbons of an asphalt-like nature which are removed as sludge acid. Upon subsequent dilution with water, the sludge acid breaks down, and upon standing, the hydrocarbons, which have been removed or formed from the original distillate, rise to the surface of the solution and may be separated from the dilute acid which is afterward concentrated and recovered for the further purification of distillates. The separated oil is usually viscous and shows a strong acid reaction. It is called acid sludge and is sometimes fractionally distilled until a semisolid residue, known as sludge asphalt, is obtained. Sludge asphalts are acted upon by water and are not generally considered suitable for use in the treatment or construction of highways. In the early days of petroleum refining they were considered as waste products and, as they could not be conveniently disposed of, they were sometimes run into large pits dug in the ground. A large deposit of this nature accumulated at an old refinery near Baltimore, Md., and there remained for many years. The sludge asphalt probably underwent considerable change in chemical and physical properties during this period and some time later this product, which had become saturated with water, was mined from the pit, heated in open kettles until fluid, the acid neutralized with caustic soda, and the resulting salt solution separated by gravity. The asphalt was then fluxed to desired consistency and used to some extent in the treatment and construction of highways. It was found to be highly resistant to water action. Such old deposits, however, are of minor importance owing to the fact that they

are of rare occurrence. The manufacture of asphalt from this source is also attended with considerable difficulty and such asphalt has not been used to any great extent.

20. The Blowing of Petroleums

Blowing Stills or Kettles used in the oxidation of petroleums for the purpose of producing asphalts are much alike in principle but may be divided into two types. (1) Those in which the air is pulled or sucked thru the charge of petroleum, and (2) those in which it is forced thru under pressure. In 1894 Francis X. Byerley patented in the United States a process for the manufacture of asphalt from petroleum by means of the action of air upon the heated material. Byerley's apparatus consisted of a cylindrical vertical still thru the head of which were inserted a number of vertical pipes extending almost to the bottom of the still and dipping well into the charge of petroleum or petroleum residuum. The upper ends of these pipes were open. A pipe or gooseneck connected the upper part of the still, or vapor space, with a coil condenser which discharged into a receiving tank. The receiving tank was hermetically closed with the exception of the inlet pipe and one other which led from the top to the suction port of an air pump. The Byerley apparatus was operated by means of the pump which created a partial vacuum in the still, thus causing the atmospheric pressure to force air thru the vertical pipes extending into the charge of petroleum and to thus thoroly agitate it with air. In 1899 the United States Patent Office granted a patent to Culmer and Culmer for a process of making asphaltic fluxes by means of the action of air upon heated petroleum residuums. The Culmer apparatus consisted of an open kettle set in brickwork over a furnace, the bottom being protected from direct fire by means of a brick arch. The kettle was provided with a draw-off, operated by a valve, and located at one end near the bottom. The petroleum was run into the kettle from a pipe which did not form a part of the apparatus proper. A vertical pipe connected with a pressure pump reached almost to the bottom of the kettle. This pipe connected with a longitudinal pipe which extended along the bottom of the kettle, and which was either perforated along its entire length or carried a number of perforated side branch pipes capped at the ends. By this means air

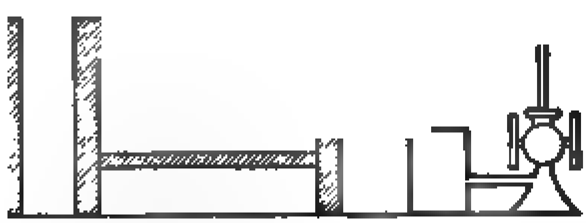
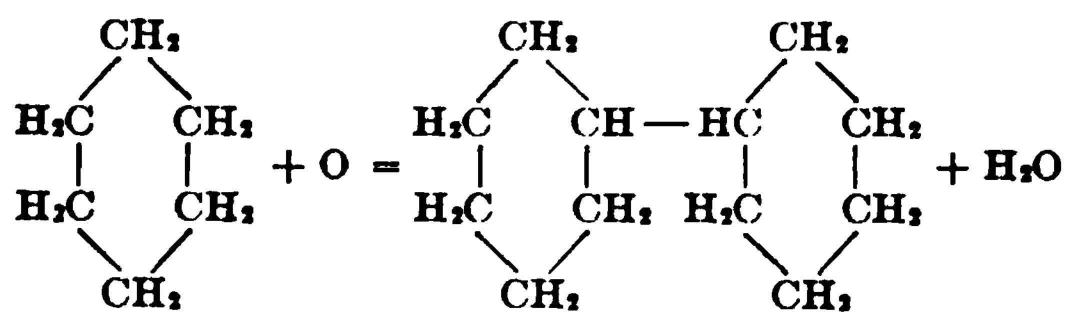


Fig. 10. Culmer Blowing Kettle

could be forced by the pump thru the piping system into the charge of petroleum residuum. The air supply was controlled by means of a valve located outside of the kettle in the main supply line. This apparatus was designed to handle non-volatile petroleum residuums and no provision was made for distillation. The Culmer type of blowing kettle is shown in Fig. 10.

In connection with this kettle a later device was used for removing any volatile products formed during the blowing process. This device consisted of a conical hood fitting closely over the top of the kettle and connecting at its apex with a large exhaust pipe thru which the volatile products were pulled by means of an exhaust pump or fan. The modern blowing apparatus holds a charge of from 2000 to 5000 gal, and makes use of the principle of injecting air, into and thru the heated petroleum, under greater than atmospheric pressure rather than to pull it thru by means of an exhaust or partial vacuum imposed upon the charge itself. The charge is often heated by means of a coil thru which is passed superheated steam instead of by direct fire. In some instances the blowing process is conducted in an horizontal cylindrical still, the dome being open and hooded. Sometimes it is conducted in an ordinary type of still fitted with piping similar to that for the injection of steam during steam distillation. In general, however, the blowing stills are not designed for the manufacture of distillates.

The Blowing Process. There are a number of variations in the blowing process as practiced in modern refineries, depending upon the character of material which is to be produced. In the preparation of bituminous materials for use in highway engineering, both semiasphaltic and asphaltic fluid petroleum residuums and soft asphalt cements are often subjected to the blowing process. The action of the air becomes very pronounced when the material is heated to about 220° C (425° F) and the air is injected so as to produce copious agitation. An exothermic reaction is then induced which often produces enough heat to make other means of heating unnecessary thruout the process. It is necessary to exercise considerable care in the manipulation of the air supply or the temperature of the charge may otherwise be raised considerably above its flash point and a serious explosion result from spontaneous combustion. The exact reactions involved are complex and varied in character. A small amount of oxygen from the air may combine with some of the hydrocarbons, but the general type of reaction seems to be one of nucleus condensation in which an atom of oxygen combines with two atoms of hydrogen or two hydrocarbon radicals which it splits off from two different molecules. It is then eliminated as water or volatile oxygen derivatives of the hydrocarbons. Meanwhile the radicals produced in the residuum join together to form a single heavier and more complex hydrocarbon. One of the simplest forms of this type of reaction may be considered as taking place between two monocyclic polymethylene molecules and one oxygen atom, with the production of a single dicyclic polymethylene and one molecule of water. Such a reaction may be graphically illustrated as follows, altho this particular reaction does not actually take place because the original hexamethylene molecules are not present in petroleum residuums but only in crude petroleums.

2. 

Owing to the formation of various radicals in the charge, exceedingly complex nucleus condensation products are probably formed which contain

a number of cycles in the molecule. In any event, even when the original material contains no hydrocarbons volatile at the temperature at which it is blown, it undergoes a marked change in many of its physical and chemical properties. If originally fluid it gradually begins to thicken and become more viscous until finally it attains semisolid consistency upon cooling. If blowing is continued, it becomes more and more solid. Its melting point increases markedly, altho its specific gravity changes but slightly. The action of the air also increases the percentage of bitumen which is insoluble in 86° B naphtha and at the same time raises its percentage of fixed carbon but to a less noticeable extent.

Blown Petroleums from Fluid Residues. If fluid petroleum residuums are blown to the consistency of asphalt cements, such cements are invariably short and non-ductile. If the original residuum was very fluid they are greasy or cheesy and lack cementitiousness. They may then have a very high melting point and at the same time show an exceedingly high penetration, or, in other words, be very soft. Blown fluid residues of the same consistency, or showing the same float test as the better types of straight distilled carpeting mediums, are wholly unsuited for use in this connection. If the original petroleum is semiasphaltic or asphaltic in character and first distilled to a very viscous residue, it may be converted to an asphalt cement possessing some cementitiousness, but not always as desirable as tho the original distillation had been carried to the production of a very soft asphalt cement and afterward blown to the desired penetration. The latter practice is fortunately in more common use.

Blown Oil-Gilsonite Asphalt Cements. One of the most satisfactory types of asphalt cement, produced primarily by blowing fluid residuums, is that which has been reinforced by combining it with gilsonite which imparts a considerable degree of adhesiveness and produces a peculiarly rubbery product. Unfortunately, it is difficult to positively identify such products by the ordinary analytical methods as products showing very

Table XI.—Gilsonite and Blown Oil-Gilsonite Asphalt Cement

Material	Gilsonite	A.C.
Specific gravity 25°/25° C (77°/77° F)	1.040	0.980
Flash point	....	205° C + (401° F +)
Penetration at 25° C (77° F)	0	85
Penetration at 4° C (39° F)	....	45
Penetration at 46° C (115° F)	....	180
Melting point	163° C (325° F)	60° C (140° F)
Ductility 25° C (77° F) cm	....	2
Loss 163° C (325° F), 5 hr, 50 g	0.4 %	0.13%
Penetration of residue at 25° C (77° F)	0	55
Soluble in CS_2 (total bitumen)	99.77%	99.91%
Organic matter insoluble	0.04%	0.05%
Inorganic matter insoluble (ash)	0.19%	0.04%
	100.00%	100.00%
Bitumen insoluble in 86° B naphtha	53.73%	25.00%
Bitumen insoluble in CCl_4	0.00%	0.03%
Fixed carbon	13.70%	9.80%
Paraffin scale	0.00%	1.60%
Sulphur	1.70%	0.70%

similar characteristics may be produced by blowing certain soft asphalt cements to harder consistency. They consist of a relatively small amount of gilsonite which is added to the contents of the blowing kettle or still after the fluid residuum has been blown to the desired melting point. It may then be cheesy or greasy and should properly be considered in the light of a very heavy flux. After the gilsonite has been added the blowing process is continued for some time before the finished product is drawn from the still. The analysis of a typical asphalt cement of this nature is shown in Table XI. The analysis of a specimen of gilsonite is also given.

Partially Blown Oil Asphalts. Fillers. If distillation of a semiasphaltic or asphaltic petroleum is carried to the production of a very soft asphalt cement, say of 300 penetration, cementitiousness is assured, and such product may then be blown to any desired lower penetration. The blowing process then imparts certain desirable properties which cannot be secured in any other way. The melting point of the asphalt cement is materially raised and its susceptibility to temperature changes is greatly lessened. It becomes more or less rubbery in character and is admirably suited for use as a seal coating material on certain types of bituminous concrete pavements containing a coarse aggregate. Such products, when prepared for use as a filler for brick or block pavements, are sometimes cast or molded into strips which may be placed in the pavement without preheating or pouring and thus serve as expansion joints. The strips may also consist of a mastic produced by combining with the asphalt cement fine mineral matter, such as limestone dust or silica. They are made of varying width and thickness to suit the different types of pavement. When not manufactured as ready prepared strips or expansion joints, the fillers have to be heated to a rather high temperature before pouring them into the joints of the pavement. Partially blown asphalt cements may usually be distinguished from asphalt cements produced by blowing fluid residuums, by their higher specific gravity and lower penetration for approximately the same melting point. They may be more or less ductile, according to the character of the asphalt cement before blowing and the length of time that they are blown. The characteristics of a partly blown asphalt cement are shown in the following analysis.

Partly Blown Asphalt Cement

Specific gravity 25°/25° C (77°/77° F)	0.999
Flash point	205° C + (401° F +)
Penetration at 25° C (77° F)	45
Penetration at 4° C (39° F)	28
Penetration at 46° C (115° F)	67
Melting point	82° C (180° F)
Ductility 25° C (77° F) cm	4
Loss at 163° C (325° F), 5 hr, 50 g	0.3 %
Penetration of residue at 25° C (77° F)	35
Soluble in CS_2 (total bitumen)	99.88%
Organic matter insoluble	0.10%
Inorganic matter insoluble (ash)	0.02%
	100.00%
Bitumen insoluble in 86° B naphtha	31.20%
Bitumen insoluble in CCl_4	0.08%
Fixed carbon	10.10%
Paraffin scale	0.40%
Sulphur	0.71%

21. The Emulsification of Petroleum Products

The Emulsifying Process. Petroleum products are insoluble in water. Unlike the vegetable and animal oils and fats, they are not directly saponifiable and will not combine with the alkalies, such as caustic soda, to produce soluble soaps. In order to produce thin, dilute emulsions of petroleum products and water it is necessary to first thoroly mix them with a soap or soap solution. Sometimes the ingredients of the soap are added separately, after which the material may be mixed with water to almost any extent. Such products are manufactured and sold as emulsifying oils. Sometimes, particularly in the case of asphalt emulsions, a certain amount of water is added during the manufacturing process so as to produce a thick viscous emulsion which may be diluted with water prior to its use in highway treatment or construction. The emulsifying agents commonly employed are commercial oleic acid, known as elaine, or cottonseed oil, in combination with caustic soda, potash or ammonia. Carbolic acid, pine oil and various other materials are sometimes used in the preparation of these emulsions for the purpose of assisting the process of emulsification. The satisfactory emulsification of asphalt cements is often a difficult matter because of the rather delicate and unstable equilibrium of the suspended bituminous material which tends to separate from the water upon slight provocation. Crude petroleums and fluid petroleum residuums are, however, not so difficult to emulsify and the apparatus is not complicated. For the preparation of such emulsions in dilute form ready for application, a hot soap solution is first prepared in a tank, the bottom of which is connected with a circulating pump which produces agitation by discharging back into the tank. The desired amount of fluid petroleum residuum is then run into the tank, the contents of which are circulated thru the pump until the emulsification is completed. The emulsion may then be further diluted if required.

Emulsifying Oils. Fluid residual petroleums which have been emulsified or prepared for emulsification can be considered only as dust layers and not as carpeting mediums whether prepared from semiasphaltic or asphaltic petroleums. They possess the advantage of easy application at almost any desired rate and have been used to a considerable extent as dust layers for park highways. In general, the manufactured emulsifying oils resemble the ordinary fluid petroleum residuums in appearance. Owing to the fact that the emulsifying agents are to a large extent soluble in carbon disulphide, they are apt to escape notice in ordinary routine examination. The products produce a brown, milky, uniform emulsion with water and, upon standing, the bitumen usually remains in suspension for a considerable period of time before separation commences. Upon application of a dilute emulsion to a road surface the water gradually evaporates and leaves behind a film of the original residuum, which is usually rather greasy in character. The characteristics of a manufactured emulsifying oil are shown in the following analysis:

Emulsifying Oil

Specific gravity 25°/25° C (77°/77° F)	0.796
Flash point	173° C (343° F)
Specific viscosity (Engler) 50 cu cm, 50° C (122° F)	23.6
Loss at 163° C (325° F), 5 hr, 20 g	14.75%
Character of residue	Fluid

Soluble in CS_2	99.80%
Organic matter insoluble	0.02%
Inorganic matter insoluble	0.00%
	100.00%
Total insoluble in 86° B naphtha	1.20%
Fixed carbon	3.90%
Ash recovered as alkaline carbonate	3.36%

Asphalt Cement Emulsions. Manufactured emulsions of asphalt cement usually contain a considerable amount of water and for this reason they are often dried at 100° C (212° F), prior to making certain physical and chemical tests. They hold an intermediate position between the petroleum dust layers or dust palliatives and the carpeting mediums. They are usually applied in dilute solution, but after the water evaporates a film of asphalt cement is left over the road surface which eventually becomes quite waterproof and refuses to again emulsify. Successive and frequent applications of such emulsions tend to produce a very thin bituminous carpet which seldom requires a covering. Emulsions of asphalt cement have also been used in the construction of cold mixed bituminous concrete pavements. When so used a considerable period of time is required for the water to evaporate sufficiently to develop the necessary consistency of bituminous cement which such highways demand. As a result, the newly constructed highway must be closed to traffic for some time and this fact has greatly limited their use in this direction. The characteristics of an asphalt cement emulsion are shown in the following analysis:

Asphalt Cement Emulsion

Specific gravity 25°/25° C (77°/77° F)	0.973
Loss in air 24 hr	6.14%
Additional loss at 105° C (221° F), 5 hr	18.62%
Dried emulsifying asphalt cement	75.24%
	100.00%
Examination of dried material	
Penetration at 25° C	221
Soluble in CS_2	96.90%
Organic matter insoluble	1.90%
Inorganic matter insoluble	1.20%
	100.00%
Insoluble in 86° B naphtha	19.94%
Fixed carbon	10.20%

The characteristics of a fluxed native asphalt emulsion, showing the emulsifying agents, are given in the following analysis:

Fluxed Native Asphalt Emulsion (42b)

Specific gravity 25°/25° C (77°/77° F)	1.038%
Loss at 105° C (221° F), 5 hr, 20 g	52.54
Penetration of residue at 25° C (77° F)	195
Additional loss at 163° C (325° F), 5 hr	3.35 %
Penetration of residue at 25° C (77° F)	72

Approximate composition

Water	49.50%
Ammonium (NH_3)	0.35%
Fatty and resin acids	9.45%
Bitumen	36.30%
Organic matter insoluble in CS_2	1.10%
Inorganic matter	3.30%
	100.00%

22. The Fluxing of Asphalts

Fluxing Tanks or Kettles may be heated either by fire or steam, the latter method being preferable because the heat may be more easily regulated and more evenly applied. It also involves less danger of overheating and thereby injuring the asphalt cement. The fire heated tanks have a rounded bottom and are set in a furnace so that the bottom is protected from direct flame by a firebrick arch. They may be either cylindrical or rectangular in shape. They are most commonly used in small portable paving plants. The steam heated kettles are used in the larger paving plants and at refineries, and are generally constructed of sheet metal. They vary in size but are usually rectangular in shape and have flat bottoms. In such tanks heat is applied by means of gangs of narrow horizontal coils carrying steam under pressure. The coils are placed in the bottom of the tank and extend up for about half its height. A number of perforated pipes, capped at one end and extending along the bottom of the tank, are used as a means of injecting live steam or air into the mass of heated material and thus securing thoro agitation, which is essential for uniform fluxing. In the fire heated kettles steam and air are also used as a means of agitation, altho in the older types mechanical agitators of the paddle-wheel type were sometimes used. Fig. 11 shows the general construction of a steam heated tank The top is left open and admits of easy filling, while a pipe operated by a valve and located at one end near the bottom of the tank serves as a draw off.

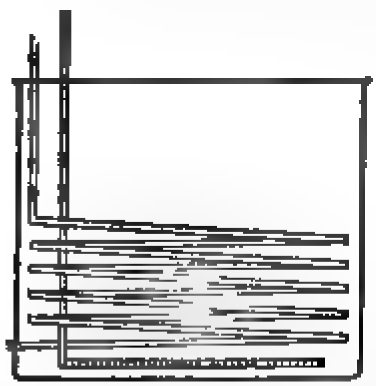


Fig. 11. Fluxing Tank

The Fluxing Process usually consists in combining a refined asphalt with a petroleum residuum or flux in such proportions as to produce an asphalt cement of any desired consistency. The refined asphalt, which is hard enough to handle in fragments, is first placed in the fluxing tank where it is melted and brought to a temperature of about 163° C (325° F) by means of the steam coils. If the tank and heating system have been properly designed, this temperature should be secured by a steam pressure of 25 or 30 lb. After the refined asphalt is melted, flux which has previously been heated to about 90° C (194° F) in another kettle is run into the tank, the contents of which are then thoroly agitated until of absolutely uniform consistency. From 3 to 10 hr, depending upon the efficiency of the agitation, are required to thoroly flux the asphalt. If air agitation is employed reactions, such as attend the blowing process, are induced to some extent with a resultant

change in the characteristics of the asphalt cement. For this reason steam agitation is often used. With steam, however, considerable care must be exercised to use only dry steam and to prevent the injection of any condensate, within the pipe, which may have resulted from previous uses. Steam agitation should not, of course, be started until the temperature of the charge is sufficiently high to prevent condensation, or otherwise serious foaming will result. In any event, at the end of the fluxing process it is advisable to finish the agitation with air injected thru the pipes which have been used for steam in order to prevent condensation within the pipes upon cooling and a resulting inflow of asphalt which will clog the perforations. It is seldom necessary or advisable to conduct the fluxing process at a temperature of over 163° C (325° F), but in no case should 205° C (400° F) be exceeded. The flux should contain but little material which is volatile at the fluxing temperature as it is difficult to control the consistency of an asphalt cement which is constantly losing appreciable quantities of its lighter hydrocarbons by volatilization. As in petroleum refining, the consistency of the asphalt cement is gaged and controlled by means of the penetration test. The approximate proportions of the refined asphalt and flux necessary to produce an asphalt cement of desired penetration are first experimentally determined by laboratory tests. In the large scale fluxing operation somewhat less than the calculated amount of flux is first used and the penetration of the resulting asphalt cement is then taken. From this penetration the additional flux required may, as a rule, be closely estimated. It has been found that, under average conditions, when making such corrections, 1 lb of flux per 100 lb of refined asphalt will soften a product of 40 or 50 penetration from two to four-tenths of a millimeter penetration. Prolonged agitation and heating tend to harden an asphalt cement or lower its penetration. At a paving plant where large batches are being slowly drawn from, it is therefore necessary to keep close watch on such change in consistency and to add more flux from time to time as needed. The physical and chemical characteristics of an asphalt cement produced by fluxing will partake of the nature of both refined asphalt and flux to some extent altho it resembles most closely the constituent which predominates. Some, but not all of the properties, are additive and may be foretold from analyses of the constituents and a knowledge of the proportions in which they are to be used. Fluxes which are suitable for one asphalt will not always produce satisfactory asphalt cements from another asphalt. In general, the heavier the flux the more is required to produce an asphalt cement of given penetration from a given refined asphalt. Light fluxes prepared from a given petroleum, as a rule, produce asphalt cements less susceptible to temperature changes than do the heavier fluxes produced from the same petroleum, but they are apt to be more volatile at elevated temperatures.

Fluxed Native Asphalts. The refined native asphalts almost invariably have to be fluxed before they are suitable for use in highway engineering In sheet asphalt construction, the preparation of asphalt cements from refined native asphalts is usually undertaken at the paving plant. Some of the asphalts are, however, fluxed by the producer and sold as asphalt cements ready for use in other types of construction. For the sake of comparison the characteristics of refined Trinidad Lake asphalt and a Trinidad asphalt cement prepared with a heavy asphaltic flux are shown in Table XII. As compared with the refined asphalt it will be noted that the asphalt cement contains the higher percentage of bitumen and lower

Table XII.—Refined and Fluxed Trinidad Lake Asphalt

Material	R.A. (8)	A.C.
Specific gravity 25°/25° C (77°/77° F)	1.400	1.210
Flash point	....	205° C+ (401° F+)
Penetration at 25° C (77° F)	7	50
Loss at 163° C (325° F)	1.0 %	1.3 %
Penetration of residue at 25° C (77° F)	....	33
Soluble in CS_2 (total bitumen)	56.53%	72.61%
Organic matter insoluble	6.97%	4.32%
Inorganic matter insoluble (ash)	36.50%	23.07%
	100.00%	100.00%
Bitumen insoluble in 86° B naphtha	36.9 %	28.4 %
Bitumen insoluble in CCl_4	0.0 %†	0.0 %
Fixed carbon	10.8 %	11.2 %
Sulphur	6.2 %	5.1 %
Paraffin scale	....	0.3 %

† About 1.3% more soluble in CCl_4 than in CS_2.

percentage of mineral matter. This is due to the fact that the flux is almost pure bitumen. Where the composition of a refined native asphalt is as uniform as Trinidad asphalt, it is possible to determine with reasonable accuracy from the characteristics of the asphalt cement not only the characteristics of the flux which has been used but also the percentage of flux. This is done from those properties which are usually additive, such as specific gravity, solubility in carbon disulphide and solubility in naphtha. According to Forrest (20c), from 21 to 60 parts of commercial flux available in 1914 to 100 parts of refined Trinidad Lake asphalt are required to produce an asphalt cement of 50 penetration at 25° C (77° F). From the analysis given above it is evident that about 60 parts of a heavy residual flux to 100

Table XIII.—Refined and Fluxed Bermudez Lake Asphalt

Material	Refined	A.C.
Specific gravity 25°/25° C (77°/77°)	1.070	1.053
Flash point	....	180° C (356° F)
Penetration at 25° C (77° F)	25	69
Melting point	....	48° C (118° F)
Loss at 163° C (325° F)	4.0%	4.3 %
Penetration of residue at 25° C (77° F)	....	36
Soluble in CS_2 (total bitumen)	95.0%	95.90%
Organic matter insoluble	2.0%	1.57%
Inorganic matter insoluble (ash)	3.0%	2.53%
	100.0%	100.00%
Bitumen insoluble in 86° B naphtha	32.1%	22.3 %
Bitumen insoluble in CCl_4	0.4%	0.7 %
Fixed carbon	18.5%	12.4 %
Sulphur	4.5%	4.3 %
Paraffin scale	....	0.2 %

parts of refined asphalt have been used in the preparation of the asphalt cement. The analyses of a refined Bermudez Lake asphalt and a Bermudez Lake asphalt cement are shown in Table XIII, while in Table XIV a Cuban asphalt and a Cuban asphalt cement are given. As neither refined Bermudez or Cuban asphalts are of as uniform composition as refined Trinidad asphalt, it is not always an easy matter to determine from an examination of these asphalt cements the characteristics of the flux and the amount which has been used. According to Forrest (20c), from 9 to 28 parts of the fluxes commercially available in 1914 to 100 parts of refined Bermudez asphalt were required to produce an asphalt cement of 50 penetration at 25° C (77° F).

Table XIV.—Refined and Fluxed Cuban Asphalt

Material	Asphalt (8)	A.C.
Specific gravity 25°/25° C (77°/77° F)	1.305	1.106
Flash point	....	205° C+ (401° F+)
Penetration at 25° C (77° F)	0	69
Melting point	....	58° C (127° F)
Loss at 163° C (325° F)	0.9%	0.7 %
Penetration of residue at 25° C (77° F)	....	45
Soluble in CS_2 (total bitumen)	75.1%	85.28%
Organic matter insoluble	3.5%	2.07%
Inorganic matter insoluble (ash)	21.4%	12.65%
	100.0%	100.00%
Bitumen insoluble in 86° B naphtha	56.7%	25.70%
Bitumen insoluble in CCl_4	0.0%†	0.12%
Fixed carbon	25.0%	13.70%
Sulphur	8.3%	....

† About 1.6% more soluble in CCl_4 than in CS_2.

Fluxed Oil Asphalts. Refined asphalts produced by the straight distillation of petroleum, are, if too hard for a given use, fluxed to asphalt cements of any desired penetration by use of a petroleum residuum flux as in the case of refined asphalts. If the flux has been prepared from the same type of petroleum and shows but little loss by the volatilization test at 163° C (325° F), it will produce an asphalt cement from the refined asphalt which is almost identical with that which would have been obtained by straight distillation of the petroleum to the same consistency. The use of different types of fluxes will of course produce from the same refined asphalt, asphalt cements of somewhat different characteristics.

Cut-Back Asphalt Cements are those which have been fluxed with a distillate. The distillate may be a light volatile fraction or a heavy non-volatile fraction. The former is more generally used, as the common reason for employing a distillate flux is to temporarily soften or liquefy an asphalt cement which has the proper penetration or consistency for a given purpose but which for one reason or another cannot readily be used in its original state in the type of treatment or construction selected. Such cut-back asphalt cements should, after use, rapidly lose the distillate flux by volatilization and acquire and maintain their original consistency. Fluid cut-back asphalt cements possess certain very desirable characteristics for surface treatment as compared with fluid petroleum residuums. They

are sometimes manufactured for use with cold stone in the preparation of bituminous concrete consisting of a coarse aggregate. In under-surface work, however, the distillate flux does not usually volatilize as rapidly as desirable. Cut-back asphalt cements may usually be identified by their relatively low flash point, high percentage loss by volatilization at 163° C (325° F) and lower temperatures, and marked hardening of the material. Because of their low flash point they should be carefully heated before use. The fluid cut-back asphalt cements prepared with a heavy non-volatile distillate are not essentially different from the fluid non-volatile petroleum residuums. They usually possess or develop but little cementitiousness. The characteristics of two cut-back asphalt cements prepared with volatile distillate fluxes, the one fluid and the other very viscous, are given in Table XV.

Table XV.—Cut-Back Asphalt Cements

	(42b)	(42a)
Specific gravity 25°/25° C (77°/77° F)	0.949	0.981
Flash point	37° C (99° F)	149° C (300° F)
Burning point	68° C (154° F)	194° C (381° F)
Specific viscosity (Engler) 50 cu cm, 25° C (77° F)	118	....
Specific viscosity (Engler) 50 cu cm, 100° C (212° F)	....	29.5
Loss at 105° C (221° F), 5 hr	16.7 %	....
Float test on residue at 50° C (122° F)	82 sec	....
Loss at 163° C (325° F), 5 hr	27.1 %	9.1 %
Float test on residue at 50° C (122° F)	100 sec	....
Penetration of residue at 25° C (77° F)	....	186
Soluble in CS_2 (total bitumen)	99.88%	99.68%
Organic matter insoluble	0.08%	0.15%
Inorganic matter insoluble (ash)	0.04%	0.17%
	100.00%	100.00%
Bitumen insoluble in 86° B naphtha	9.10%	17.00%
Bitumen insoluble in CCl_4	0.00%	0.00%
Fixed carbon	4.90%	7.10%

Cut-back asphalt cements of any degree of fluidity may be prepared by adding the proper amount of suitable distillate. When gasoline is used as a cutting-back medium in considerable amount, it should preferably be a heavy gravity gasoline produced from an asphaltic petroleum and consisting mainly of polymethylene hydrocarbons which are much better solvents for the asphalt cement than are paraffin gasolines. The paraffin gasolines are only partial solvents and their use may result in the precipitation of the solid asphaltic hydrocarbons, thus producing a material which lacks in uniformity and in which the ultimate cementing value may be poor, altho the original asphalt cement was of good character.

ROCK ASPHALTS

23. Production of Rock Asphalts

The Occurrence of Rock Asphalts has been covered to some extent under native asphalts, and statistics of their production and importation by the United States for 1910 to 1913 inclusive are given in tables in Art. 17,

The production for various European countries is included in the figures for all semisolid and solid native bituminous materials. As the true native asphalts occur to only a limited extent in Europe, these figures mainly represent bituminous rock or rock asphalt. Italy and France are the two largest producing countries and Germany ranks third. Owing to the comparatively small amount of bitumen which they contain and to the high cost of transportation but little European rock asphalt finds its way into the United States, altho some has been imported for use in the paving industry, and was employed in this connection as early as 1876 at Washington, D. C. Considerably earlier in the 19th century rock asphalts were used in the construction of sidewalks and pavements in the European countries but its success in this connection was not pronounced until 1854. The term asphalte is commonly applied to these products in Europe but not in the United States. Rock asphalt usually consists of limestone or sandstone impreganted with maltha or asphalt, its origin and formation being similar to these materials except that as mined the bitumen constitutes only a relatively small percentage of the product obtained. Those in common use contain from 6 to 14% bitumen. One of the earliest discovered and operated deposits is located at Val de Travers, Neufchatel, Switzerland. This deposit of bituminous limestone was worked as early as 1712. In France, large deposits of bituminous limestone occur at Seyssel, Autun, Aumance, Ain, Gard, Puy-du-Dôme, Levagny, Mons and Haute-Savoie, of which the Seyssel deposit was opened about 1797. In Italy, bituminous limestone occurs in paying quantities, and on the Island of Sicily at Ragusa, Syracuse, Catania and Mazzarelli. Both bituminous limestone and bituminous sandstone occur in Germany, the principal deposits being at Lobsann in Alsace and at Limmer and Vor Wohle. Other European deposits are located in Spain at Maester; in Russia at Syzran, Samara and on the island of Tchelekin; in Greece near Marathonopolis, and at a number of localities in Turkey. Deposits are found widely distributed over the United States and Canada, the more important being located in the States of Texas, Oklahoma and Kentucky.

Mining Rock Asphalts. The general methods of mining or quarrying rock asphalt are not unlike those for ordinary rock quarrying. As some rock asphalts become adhesive and gummy in warm weather, making it difficult to drill holes for the blasting charge, the quarrying may be carried on in underground tunnels except in cold weather, when it may be blasted. The exact method of mining varies somewhat with the character of the rock asphalt as some, particularly the bituminous sandstones, are loose-grained and friable and almost wholly dependent upon the bitumen to hold the individual mineral particles together, while others are hard and dense, the rock being merely saturated with bitumen.

Preparation of Rock Asphalt. After coming from the quarry the rock asphalt is crushed or broken into small lumps which may either be shipped as such or else further reduced. It is usually crushed between toothed or grooved steel cylinders known as roll crushers but sometimes by centrifugally operated flail or hammer crushers. In order to obtain a product suitable for direct use in highway work it is sometimes necessary to combine two or more grades of rock asphalt containing different percentages of bitumen. By this means the proper percentage of bitumen for the particular character of aggregate may be secured. The blending or mixing is often carried on in a large revolving mixing cylinder or kettle in which the rock is heated to a temperature of about 100° or 125° C (212° or

257° F.) Sometimes a rock asphalt is enriched by the addition of asphalt and, if the natural bitumen is harder than desirable, a petroleum residuum or flux is used to soften it to suitable consistency.

Transportation of Rock Asphalt. The harder grades of rock asphalt may be most conveniently shipped in the lump form, in which case, however, they usually have to be crushed or prepared for use upon arrival at their destination. They are commonly transported by rail or as ballast in vessels. It is seldom economy, however, to ship them long distances. If shipped in pulverized or prepared form the mass of originally loose particles is apt to congeal and compress under its own weight so that in unloading it has to be handled with pick and mattox and afterwards warmed before it may be separated to its original prepared condition. Upon long storage it almost invariably congeals to a solid mass. The crushed bituminous sandstones are usually easier to handle than the limestones, owing to their coarser texture.

24. Characteristics of Rock Asphalts

Bituminous Limestones are more or less pure limestones or calcium carbonate impregnated with bitumen. They may be of a semicrystalline, conglomerate or chalky nature, and contain varying percentages of sand and other mineral substances. The purer carbonate rocks crush down to a fine powder, each particle of which appears to be impregnated with bitumen. This powder is often of a brownish color and appears dry, altho it may contain as high as 15 or 16% bitumen. Under compression, and especially at an elevated temperature, the better grades congeal to form a dense tough mastic composed of very fine mineral particles cemented together with the bituminous cement. The bitumen may vary in consistency from a soft maltha to a hard brittle asphalt. It is, however, a difficult matter to recover the bitumen so as to positively identify its original consistency. This is due to an almost unavoidable hardening which it undergoes during the laboratory extraction and recovery process. The percentage of bitumen varies widely but in the better grades of commercial products is seldom less than 7 or 8%. Analyses showing the percentage of various constituents present in typical European bituminous limestones as given by Howard (22) are shown in Table XVI. It should be remembered, however, that the percentage of bitumen present in rock from different parts of the same deposit often varies considerably.

Table XVI.—Analyses of European Bituminous Limestones

Constituents	France		Italy		Sicily
	Seyssel	Mons	St. Volentino	Cesi	Ragusa
Bitumen	8.15	10.20	8.83	7.15	8.92
Calcium carbonate	91.30	84.63	80.00	73.76	88.21
Magnesium carbonate	0.10	......	......	......	0.96
Sand or insol. in HCl	0.10	......	......	14.34	0.60
Alumina and iron	0.15	......	......	......	0.91
Sulphur	......	......	......	3.02	......
Undetermined	0.20	5.17	11.17	1.73	0.40
Total percent	100.00	100.00	100.00	100.00	100.00

Table XVI.—Continued

Constituents	Germany			Switzerland	Russia
	Limmer	Lobsann	Vor Wohle	Val de Travers	Syzran
Bitumen	14.30	12.32	8.50	10.15	30.50
Calcium carbonate	67.00	71.43	80.04	88.40	66.23
Magnesium carbonate	17.52	0.31	0.55	0.30	3.27
Sand or insol. in HCl	......	3.15	4.77	0.45	......
Alumina and iron	......	5.91	......	0.25	......
Sulphur	......	5.18	4.03	......	......
Undetermined	1.18	1.70	2.11	0.45	......
Total percent	100.00	100.00	100.00	100.00	100.00

An analysis, as made by the U. S. O. P. R., of a typical specimen of an important American bituminous limestone deposit occurring in Uvalde County, Texas, is given below. This product is a shell limestone or conglomerate impregnated with a hard asphalt as shown by the characteristics of the recovered bitumen. In this material, which after preparation has been used quite extensively in highway construction, accumulations of almost pure bitumen are frequently found in the small shell pockets of the conglomerate.

Analysis of Texas Bituminous Limestone

Specific gravity	2.173
Soluble in CS_2 (total bitumen)	13.10%
Insoluble matter	86.90%
	100.00%

Examination of recovered bitumen:

Specific gravity 25°/25° C (77°/77° F)	1.091
Penetration at 25° C (77° F)	10
Melting point	86° C (187° F)
Bitumen insoluble in 86° B naphtha	49.25%
Fixed carbon	16.51%
Ash	0.48%

Bituminous Sandstones are usually of much coarser texture than bituminous limestones and, while the bitumen permeates the natural rock, it appears rather to coat the mineral particles than to impregnate them. In their preparation for use the sand grains are not necessarily crushed to produce a mastic with the bitumen, but may be merely broken down or partly separated. A prepared bituminous sandstone may therefore have the general appearance of a sheet asphalt paving mixture altho the mineral particles seldom show the grading considered most desirable for sheet asphalt work. The percentage of various constituents of a Spanish rock asphalt as given by Howard (22) is shown in the following analysis:

Analysis of Maester Bituminous Sandstone

Bitumen	8.80%
Sand	68.75%
Calcium carbonate	9.15%
Magnesium carbonate	8.10%
Alumina and iron	4.35%
Undetermined	0.85%
Total	100.00%

The analysis of a typical American bituminous sandstone prepared from material obtained from an extensive deposit in Kentucky is given below. The bitumen recovered from this product was found to be a viscous sticky maltha which hardened to semisolid consistency under the volatilization test. The characteristics of the recovered bitumen as well as the mechanical analysis of the mineral matter is given. The percentage of bitumen in different parts of the same deposit varies considerably, and this is generally true of all large deposits.

Analysis of Kentucky Bituminous Sandstone

Soluble in CS_2 (total bitumen)	6.73%
Mineral matter insoluble	93.27%
	100.00%
Examination of recovered bitumen:	
Specific gravity 25°/25° C (77°/77° F)	1.027
Loss at 163° C (325° F), 5 hr, 20 g	5.41%
Bitumen insoluble in 86° B naphtha	17.90%
Fixed carbon	10.80%
Ash	1.76%
Examination of recovered aggregate:	
Passing 200-mesh sieve	3.5%
Passing 100-mesh sieve	4.5%
Passing 80-mesh sieve	4.5%
Passing 50-mesh sieve	35.0%
Passing 30-mesh sieve	43.0%
Passing 20-mesh sieve	5.5%
Passing 10-mesh sieve	3.0%
Retained on 10-mesh sieve	1.0%
	100.0%

CRUDE TARS

25. Formation of Tars

Sources of Tar. The term tar has been applied to many black viscous materials consisting mainly of hydrocarbons and their derivatives, whether produced by destructive distillation or not. Thus viscous residues produced by the preliminary fractional distillation of petroleums, which residues are later distilled to coke in a separate still, are sometimes known as tar to the petroleum refiner. As generally accepted, however, the term is confined to bituminous distillates produced by the destructive distillation of almost any organic material providing that, upon being themselves subjected to fractional distillation, these distillates will yield semisolid or solid residues known as pitches. Tars thus differ materially from bituminous distillates produced by fractional distillation, as the latter cannot again be fractionally distilled so as to produce semisolid or solid residues. The sources of tar which are of particular interest in highway engineering are bituminous coal and petroleums. Both are largely used in the manufacture of illuminating gas and the former is also consumed in immense quantities in the manufacture of coke. Both gas and coke are produced by the destructive distillation of these substances and the tar is obtained as a by-product. Other substances of a non-bituminous nature usually accompany the formation of tar and often occur as impurities in the crude tar. As in the case of other crude bituminous materials the impurities are more or less completely removed by refining processes.

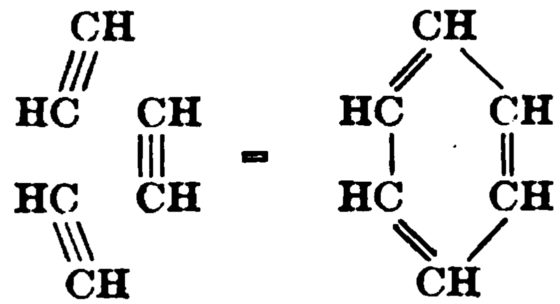
Formation of Tar Hydrocarbons from Coal. The high temperatures involved in destructive distillation are particularly favorable to the forma-

tion of liquid and solid hydrocarbons belonging to the unsaturated cyclic and polycyclic series. The proportion and, to a considerable extent, the character of such hydrocarbons produced from coal vary with the character of the coal distilled and the particular conditions of time, temperature and pressure which attend the process. In general, however, hydrocarbons of the benzene, C_nH_{2n-6}, naphthalene, C_nH_{2n-21}, and anthracene, C_nH_{2n-18} series predominate, altho members of many of the other unsaturated open chain and cyclic series are also found in varying proportions. Coals themselves are complex mixtures of hydrocarbons, the molecular composition of which is little understood. It is, however, definitely known that coal tar is not a simple mixture of the volatile constituents of the coal, but that it is the product of complex chemical reactions that take place during the process of carbonization or destructive distillation. The probable character of the reactions involved are more or less speculative, but it is reasonable to suppose that, at the very high temperatures employed the volatile hydrocarbons of the coal dissociate into radicals such as CH_3—, $CH_2 =$ and $CH \equiv$. If nascent or atomic carbon, $C \equiv$, and hydrogen H—, are also split off, as seems probable, the formation of almost any of the hydrocarbons actually present in tars may be readily explained. The primary hydrocarbons formed contain one or two carbon atoms to the molecule and therefore consist of methane, CH_4, ethylene, C_2H_4, and acetylene, C_2H_2, first members of their respective series. Under suitable conditions these hydrocarbons react, break down or polymerize during the distillation process to form members of other, and often more complicated series of hydrocarbons. The general nature of the initial reactions, many of which are reversible, may be shown as follows:

$$
\begin{array}{lrcl}
 & 2CH_4 & = & C_2H_6 + H_2 \\
\text{or} & 2CH_4 & = & \underline{C_2H_2} + 3H_2 \\
 & C_2H_6 & = & C_2H_4 + H_2 \\
\text{or} & 2C_2H_6 & = & \underline{C_2H_2} + 2CH_4 + 2H_2 \\
 & C_2H_4 & = & C_2H_2 + H_2 \\
\text{or} & 2C_2H_4 & = & \underline{C_2H_2} + C_2H_6
\end{array}
$$

It will be seen that there is a general tendency to form acetylene which readily polymerizes to form the volatile liquid benzene, which may be graphically shown as follows:

$3C_2H_2$ or



The formation of naphthalene and anthracene thru the reaction of benzene and acetylene are given in the following equations:

$$C_6H_6 + 2C_2H_2 = C_{10}H_8 \text{ (naphthalene) } + H_2$$
$$2C_6H_6 + C_2H_2 = C_{14}H_{10} \text{ (anthracene) } + 2H_2$$

These reactions explain why tars produced by the destructive distillation of entirely different original substances, such as coal and petroleum, may

be and often are similar in chemical and physical properties. Whatever the exact nature of these reactions may be, it is certain that at very high temperatures an ultimate decomposition of the vaporized hydrocarbons takes place with the formation of free carbon and free hydrogen. While the resulting hydrogen is found in the permanent gases, a large proportion of the carbon is deposited in the tar as an inert impurity. At lower tem-

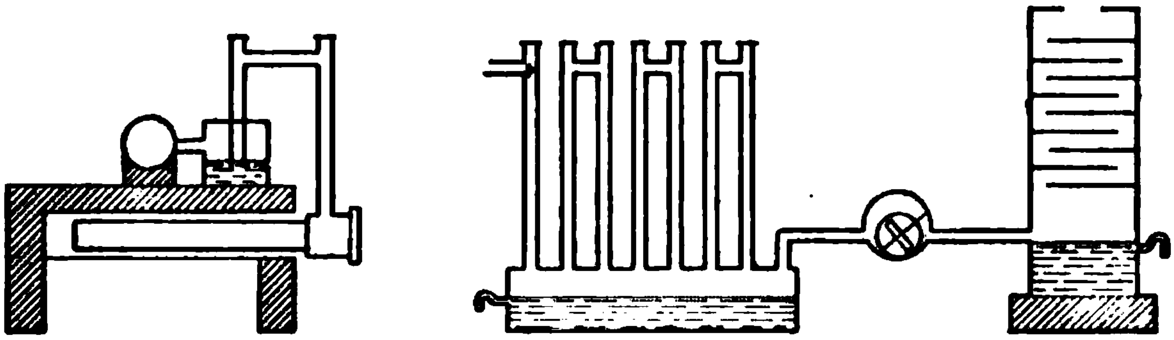


Fig. 12. Coal-Gas Plant

peratures ultimate decomposition of the vaporized hydrocarbons becomes less, so that tars produced at relatively low temperatures contain less free carbon than those produced at the higher temperatures. If the substance originally subjected to destructive distillation contains oxygen, sulphur or nitrogen, these elements are usually found in the tar as oxygen, sulphur or nitrogen derivatives of some of the tar hydrocarbons. Practically all bituminous coal contains oxygen and some of this oxygen during destructive distillation combines to form phenols and cresols which appear in the tar.

Manufacture of Coal Tar. The general principles of coal tar manufacture are the same whether conducted in a gas-house with horizontal, inclined or vertical retort, or in a by-product coke-oven. While the details of plant apparatus and operation vary somewhat, and therefore the character of the resulting tar, the general plan of operation may be illustrated by the gas-house process with horizontal retort. A diagram of the principal parts of such a gas-house plant is shown in Fig. 12. In the manufacture of illuminating gas, bituminous coal is first placed in horizontally set semi-oval fire-clay retorts about 8 ft long, 15 in high, and 18 in wide at the bottom. A battery of six or eight of these retorts set together in a brick furnace constitutes a bench, and a number of benches built together is called a stack. The retorts are charged from one end and after charging all openings are closed with the exception of a vertical stand-pipe extending upwards from the front and connecting by a bridge with a vertical dip pipe. The dip pipes from all of the retorts in a stack connect with a long covered trough running the entire length of the stack and known as the hydraulic main. The hydraulic main is partly filled with water which serves as a seal for the outlet of each dip pipe. Upon heating the retorts, which have been partly filled with coal, volatile hydrocarbons are produced and these hydrocarbons in the gaseous state react within the retort to form the types of products treated of in the preceding paragraph. As the gases are evolved they pass thru the standpipe, bridge and dip pipe into the hydraulic main where a considerable proportion of the liquefiable hydrocarbons condense under water. As the tar collects it is drawn off by various ingenious devices upon reaching a certain height in the hydraulic main. The gas from the hydraulic main passes thru a pipe to the condenser which usually consists of a series of vertical cast-iron pipes

connected at the top and opening at the bottom into an iron box, which is divided by transverse partitions extending nearly to the bottom and dipping into water or former condensates, so that the gas is forced to pass thru all of the pipes. The condenser is cooled either by air or water so that the gas is slowly brought to a temperature of 50° C (122° F). More of the liquefiable hydrocarbons condense here. The gas is drawn thru the condenser and forced thru the remainder of the purifying apparatus by means of a mechanical device called the exhauster, which serves to prevent back pressure upon the retort. From the exhauster, the gas passes thru a tar extractor or scrubber, consisting of a tower fitted with numerous perforated horizontal plates or other device, where the last traces of tar vapor are condensed and removed by friction. From this point on the process of gas manufacture ceases to be of interest so far as the production of tar is concerned. The finished gas consists of a mixture of hydrogen and incondensable hydrocarbons such as methane, while coke or relatively pure carbon and any mineral matter present in the original coal remains in the retort. Approximately 60% of all the tar produced condenses in the hydraulic main, 15% in the condenser, and 25% in the scrubber. As would naturally be expected, the heavier and more viscous liquid hydrocarbons condense first in the hydraulic main, and the lighter and more fluid products in the scrubber. As the tar is drawn off from the various parts of the plant, however, it is usually run into a common well or storage tank where it is allowed to settle for some time in order to separate it as completely as possible from water and other impurities. The character of the tar itself is largely influenced by the temperature employed in the destructive distillation of the coal, which lies between 850° and 1540° C (1562° and 2804° F). Up to 970° C (1778° F) is commonly considered low temperature, from 970° to 1100° C (1778° to 2012° F) medium temperature, and above 1100° C (2012° F) high temperature. The yield of tar per ton of coal varies greatly, but in American practice averages from 7½ to 10½ gal. In general, the higher the temperature of destructive distillation the greater the yield. As the temperature of distillation increases, the percentage of free carbon in the tar increases and also the percentage of hydrogen in the gas. This is due to the more complete decomposition of the hydrocarbons at high temperature. The viscosity of the tar also increases with the temperature of distillation. The effect of temperature and other conditions is further considered under the various classes of tar in Art. 27.

Formation of Tar Hydrocarbons from Petroleum. From the preceding paragraph it is evident that the formation of the hydrocarbons occurs under entirely different conditions of temperature, pressure and time than the formation of petroleum hydrocarbons. Thus tars are produced rapidly at high temperatures and low pressures, while, as shown in Art. 13, petroleums are formed very slowly at low temperatures and high pressures. If, however, petroleums or petroleum products are themselves subjected to high temperatures and low pressures, the hydrocarbons crack or dissociate in much the same way as the coal hydrocarbons, with the formation of ultimate products quite similar and in many respects identical with the products of the destructive distillation of coal.

Manufacture of Water-Gas Tar. Water-gas tar is a by-product incidentally manufactured during the process of carburetting water-gas by means of destructively distilling or cracking at high temperatures certain classes of petroleum or petroleum products known as gas oils. The straight water-gas is produced by the reaction between steam and incandescent car-

bonaceous material, such as coke or anthracite coal, without the production of hydrocarbons. This reaction is commonly written $C + H_2O = CO + H_2$. As no hydrocarbons are formed in this process there can be no formation of tar. The straight water-gas, which consists of a mixture of carbon monoxide and hydrogen, burns with a non-luminous flame and, in order to make it a true illuminating gas, it is necessary to enrich it by the introduction of gaseous hydrocarbons. This is usually accomplished with one of the distillates of petroleum known as gas oil which is cracked in contact with the water-gas by what is known as the carburetting process. The gas oil is thus converted into permanent gaseous hydrocarbons and liquefiable hydrocarbons which ultimately condense to produce tar. The origin of water-gas tar is therefore petroleum. A diagram of the principal parts of a carburetted water-gas plant is shown in Fig. 13. In the process of water-gas manufacture the coke or anthracite coal is first heated to redness in a large cylindrical metal chamber called the generator. Air is then admitted to the generator thru a blast pipe and passes thru the incandescent fuel with which it reacts to form producer gas. The hot producer gas passes out of the generator into the top of a second cylindrical chamber called the carburettor where it meets a blast of air from another pipe connected with the source of air supply. Here it is partly oxidized and the resulting heat of combustion raises the temperature of the checkerwork of brick which fills the carburettor. The unconsumed gas and products of combustion then pass from the bottom of the carburettor into the bottom of a third and taller cylindrical chamber called the superheater which is also filled with a checkerwork of brick. Here the unconsumed gases are entirely oxidized by air admitted thru another blast pipe. The products of combustion then escape thru a stack valve at the top of the superheater. This process is only preliminary to the actual manufacture of water-gas and is continued just long enough to bring the fuel in the generator to a bright red heat and the brick checkerwork in the carburettor and superheater to proper temperature to cause cracking of the petroleum hydrocarbons later introduced. When this is accomplished, steam is admitted to the generator thru a small pipe, all of the air blasts are shut off and the stack valve on the superheater closed. Plain water-gas is formed in the generator by the action of the steam upon the incandescent fuel and passes into the carburettor, where it meets a spray of gas oil introduced thru a pipe at the top. The oil is here gasified and carried by the water-gas into the superheater, where it is cracked or broken up into permanent hydrocarbon gases by the high temperature of the brickwork and also into heavier hydrocarbons which later condense as tarry products during the process of gas purification. The carburetted water-gas passes thru a pipe near the top of the superheater to condensers and scrubbers similar to those described under the MANUFACTURE OF COAL TAR.

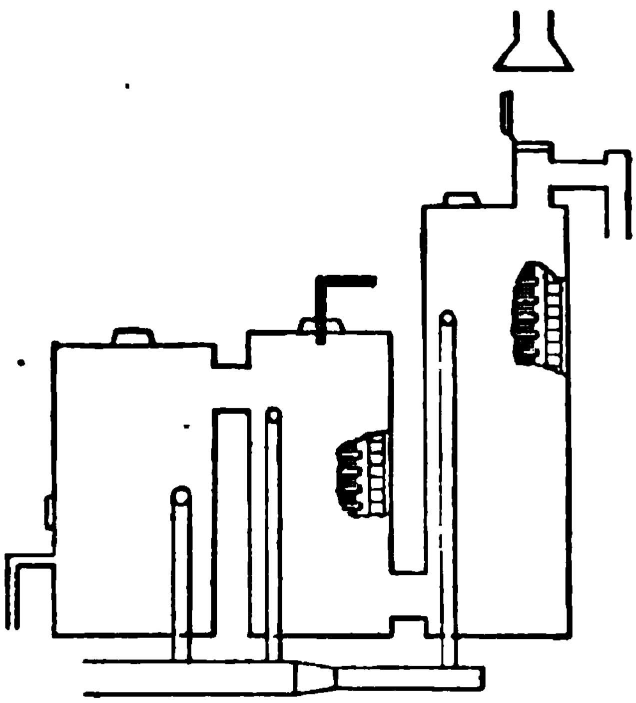


Fig. 13. Carburetted Water-Gas Plant

Here the tar is deposited and is afterwards run into storage tanks. The character of the tar is considerably influenced by the character of oil which is used, and as in the case of coal tar, by the temperature at which it is produced. The yield of tar varies from 2 to 18% by volume of the oil used for carburetting. For the ordinary petroleum distillate gas oils it will average about 10%. While the average temperature of cracking or distillation of carburetted water-gas manufacture is higher than for coal-gas manufacture, the maximum temperature is lower and for this reason, as well as the fact that cracking is produced in an atmosphere rich in hydrogen, the water-gas contains a lower percentage of free carbon than coal tar. A greater proportion of light condensable hydrocarbons is also produced so that the crude water-gas tar is much more fluid than crude coal tar.

26. Production of Tars

Production of Tar in the United States. Statistics relative to the production of tar in the United States are neither as complete nor available as those for the production of petroleum. The production is so widely distributed and there are so many small plants which do not keep an accurate record of their tar manufacture that reliable information is difficult to secure. In the early days of gas manufacture, tar was considered as a waste product and proved to be a source of nuisance not only to the manufacturer but to the public, as it was often run into rivers and streams, causing pollution of the water. Later it was discovered that many valuable products could be obtained by its fractional distillation and chemical treatment. From a waste product it therefore gradually became a valuable by-product and is now accumulated and sold by most gas manufacturers who do not use it as fuel in their manufacturing processes. Statistics of the production of tar were first compiled by the United States Government in 1898, and since then reports on the subject have been issued at irregular intervals. In these reports coal tars are divided into two groups those produced at gas works and those produced at by-product coke-oven plants. The tars produced and sold at water-gas and oil-gas works are considered collectively. The production of these tars from 1904 to 1913 for the years recorded is given in Table XVII.

Table XVII.—Production and Sale of Tar in the United States, 1904–1913, in Gallons

Year	Coal Tar			Water-Gas and Oil-Gas Tar	Total
	Gas-House	Coke-Oven	Total		
1904	41 726 970	27 771 115	69 498 085	....	....
1905	43 642 189	36 379 854	80 022 043	....	....
1907	49 581 965	53 995 795	103 577 760	....	....
1908	58 541 220	42 720 609	101 261 829	9 168 834	110 430 663
1912	40 489 855	94 306 583	134 796 438	33 930 273	168 726 711
1913	....	115 145 025	....	....	....

A comparison of the production for 1908 and 1912 is particularly instructive as showing the general trend of development. From these figures it will be noted that in 1908 gas plants were the most important source of

supply of coal tar, while in 1912 the production from this source had notably decreased. This was in large measure due to the increasing use of carburetted water-gas and the introduction of carburetted water-gas manufacture at many plants where coal-gas was still produced. A very great increase in the production of water-gas tar for this period is shown, as water-gas tar constituted by far the largest proportion of tar produced from petroleum or oil. It is seen that the production of water-gas tar for 1912 closely approached that of gas-house coal tar, while in 1908 it was of rather minor importance. The most remarkable development is however shown by by-product coke-oven tar, the production of which was increased by over 50 000 000 gal. A continued marked increase is shown for 1913. Coke-oven tars are in general admirably adapted to the manufacture of road and paving materials. Their production in the United States dates only from 1893, when twelve by-product coke-ovens were constructed at Syracuse, N. Y. By the end of 1912 over 5000 by-product coke-ovens were in operation, and the future production of tar from this source promises to become of even greater relative importance. Immense quantities of coke have been and are being coked in the old beehive type of oven, in which no attempt is made to recover any portion of the coal which is volatilized during destructive distillation. In beehive coke-oven practice, all tar hydrocarbons which are formed are wastefully burned at the outlet of the oven. Some idea of the tremendous loss in tar production by this process may be obtained by the relative amount of coal coked and tar produced therefrom in the by-product coke-ovens. In 1913 the by-product ovens produced 115 145 025 gal of tar from 17 089 700 tons of coal. During the same year 52 150 400 tons of coal were coked in beehive ovens without recovery of tar. Upon the same basis of yield as for the by-product coke ovens, this represents a loss of nearly 350 000 000 gal of tar or over twice the total production of all classes of tar for the preceding year. The encouraging advance of by-product coke-oven practice over that of the beehive oven is shown by the fact that in 1908 of the total coke produced that from by-product ovens amounted to about 16%, while in 1912 it exceeded 27%. A corresponding decrease in percentage of total coke production from beehive ovens occurred during that year. In regard to the actual total production of all types of tar in the United States, it is of interest to note that the gallonage for 1912 amounted to less than 2% of the total production of petroleum in the United States for that year.

Production of Tars in European Countries. The tar industry did not assume any considerable proportions until a number of years after the erection of the first coal-gas works in England in 1798. The first public gas works made their appearance in London in 1813, in Paris in 1815, and in Berlin in 1826. It was not until 1838, however, that the utilization of tar and tar products began. By 1883 it is estimated that England was producing between 70 000 000 and 90 000 000 gal of coal tar, Germany about 17 000 000, and France about 15 000 000 gal. Belgium and Holland were then producing considerably smaller amounts. Meanwhile, various types of by-product coke-ovens began to come into quite general use. By 1900 it is estimated that the entire world was producing about 450 000 000 gal of coal tar and oil tars. England has always maintained the lead in production for the European countries, altho Germany has been most active in developing the utilization of tar products in general. The approximate production of all gas-house tars and coke-oven tars for the United Kingdom from 1900 to 1907 is given in Table XVIII. A comparison of these

Table XVIII.—Approximate Production of Tar in the United Kingdom, 1900–1907, in Gallons

Year	At Gas Works	At Coke-Oven Works	Total
1900	138 000 000	10 000 000	148 000 000
1901	140 000 000	11 000 000	151 000 000
1902	141 000 000	14 000 000	155 000 000
1903	142 000 000	16 000 000	158 000 000
1904	142 000 000	18 000 000	160 000 000
1905	145 000 000	27 000 000	172 000 000
1906	150 000 000	39 000 000	189 000 000
1907	....	48 000 000	....

figures with those of Table XVII shows that as far back as 1905 the United Kingdom was producing over twice as much as the United States and more than the United States produced in 1912. It is estimated that in 1907 Germany produced some 180 000 000 gal of tar. From the figures given it will be seen that the four leading tar producing countries of the world are England, Germany, the United States and France, in the order named.

Transporation and Storage of Crude Tar. At gas works crude tars are sometimes collected and stored in underground tanks or wells and sometimes in the bottom of large gas holders. Here much of the water and water-soluble impurities separate by gravity so that the crude tar sold to the tar refiner has been partially dehydrated by sedimentation. The crude tar is transported to the refineries by various means. When the refinery is located close to the gas or coke-oven works the tar may sometimes be run thru pipe lines, but this method of transportation is not satisfactory for long distances as in the case of petroleum transportation because many tars become extremely viscous at low temperatures. From the smaller gas plants tar is often transported in railroad tank cars of approximately 10 000 gal capacity. Whenever possible, however, water transportation is employed and the tar is shipped in tank barges of from 25 000 to 300 000 gal capacity. Upon reaching the refinery the tar is run by gravity or pumped into storage tanks similar to those used for the storage of petroleum. Tank cars, tank barges and the storage tanks are often equipped with steam coils for the purpose of warming the tar if necessary to facilitate its rapid handling. At a modern refinery the storage tanks range from 250 000 to 2 000 000 gal capacity. Where large quantities of tar from a single source of supply are handled, the larger tanks are employed. Where tars of varying characteristics are obtained from many sources, the smaller tanks are used to keep the different types and grades separate. The storage tanks are cylindrical in shape and set on end, usually upon a concrete base. They are constructed of steel with the exception of the roof, which is generally of wood, as the vapors from the tar are particularly corrosive to steel but non-injurious to wood. The wooden roofs are waterproofed to keep out rain water. Outlet cocks are placed on the sides of the tanks at varying heights in order to drain off water which may rise to the surface of the crude tar during storage. The crude tar is piped directly to the dehydrating plant or still for refining.

27. Classification of Tars

General Characteristics. There are many classes of tars which vary greatly in character, among which may be mentioned those produced by the destructive distillation of wood, peat, lignite, bituminous coal, bituminous shale, petroleum, animal fats, vegetable fats, rosin, bone, molasses and alcoholic residues. As previously stated, those of particular interest in highway engineering are coal tars and petroleum tars, of which latter group the carburetted water-gas tars are of most importance. The three groups which should receive special consideration are gas-house coal tars, coke-oven tars and carburetted water-gas tars. All of these tars are similar in composition but variations in the relative proportions of the individual constituents cause wide variations in their physical and chemical properties. The ultimate analysis of these tars is not greatly different from crude petroleums, altho in the case of coal tars oxygen and nitrogen are always present in greater amount. Their specific gravity usually varies from 1.05 to 1.30 and slightly higher and their viscosity generally increases with their specific gravity. The lighter varieties are thin, oily, brown fluids, while the heavier tars are very viscous, black, sticky substances. They all have a rather unpleasant acrid odor quite distinct from the odor of crude petroleum. The odor of coal tar can usually be distinguished from that of water-gas tar by the presence of phenolic or carbolic vapors. Moreover, crude coal tar always contains as an impurity water carrying ammoniacal salts in solution, known as ammoniacal liquor, while water-gas tar does not, owing to the absence of appreciable quantities of nitrogen in the oil from which it is produced. All crude tars carry variable quantities of light volatile hydrocarbons which evaporate upon exposure. When freed from water and water-soluble impurities, many of them still hold appreciable quantities of free carbon suspended in a very finely divided state. This material is insoluble in carbon disulphide and runs from a few tenths of one per cent in water-gas tars to 30% and over in coal tars produced at high temperature. As they have been produced primarily as distillates they yield little or no ash upon ignition. Crude tars as delivered at the refinery seldom contain over 10% of water unless they carry a very high percentage of free carbon, in which case water to the extent of 20% or more may be retained by the tar. The very fluid low carbon tars tend to separate from water much more readily and may contain 1% or less. They are powerful solvents for nearly all bituminous materials, including petroleums and asphalts but in general and unlike petroleums their solvent action decreases somewhat as their specific gravity increases. As a rule, their coefficient of expansion varies inversely with their specific gravity, but according to Weiss (44) lies between 0.000305 and 0.000375 per degree C. Their specific heat usually lies between 0.3 and 0.4. Further characteristics of the more important classes and groups of tars are given in succeeding paragraphs.

Gas-House Coal Tars are tars produced by the destructive distillation of bituminous coal primarily for the manufacture of gas. The object of the gas manufacturer is to obtain as much gas as possible from a given quantity of coal and for this reason the temperature of distillation is carried very high. As practiced in the United States this tends to produce high carbon tars. As the quality of gas produced at high temperatures is deficient in illuminating value, it is often enriched with carburetted water-gas. The manufacturer, therefore, frequently produces both coal tar and water-gas tar which he runs into a common storage tank. When such practice

is followed, the resulting tar is not a gas-house coal tar but a mixture of tars. There are three general types of retort used in gas manufacture, known as horizontal, inclined, and vertical. The horizontal retort is almost exclusively used in the United States, altho some few plants operate the other types. In European countries the use of vertical retorts is rapidly increasing, especially in England and Germany. Gas-house tars produced in the different types of retorts vary greatly in character owing to variations in the resulting conditions of distillation. In general, inclined retorts produce tars containing a lower percentage of free carbon than do the horizontal retorts, and the vertical retorts produce quite low carbon tars, which in this respect resemble most of the coke-oven tars. Figs. 14, 15, and 16 are diagrams showing the relative proportions of certain constituents in typical crude gas-house coal tars free from water, which have been produced from horizontal, inclined and vertical retorts. In these diagrams the area below the line *a a* represents soft refined tar residue of about 60° C (140° F) melting point produced by distilling off a sufficient amount of the more volatile constituents. The white area A represents the saturated hydrocarbons present in the distillate which are unattacked by concentrated sulphuric acid. Area B represents the unsaturated hydrocarbons in the distillate, and area C the oxygenated hydrocarbons or phenols and cresols removed with a

Fig. 14. Horizontal Retort Tar

Fig. 15. Inclined Retort Tar

Fig. 16. Vertical Retort Tar

solution of caustic soda. Area D shows the amount of heavy pitch bitumen composed almost entirely of unsaturated hydrocarbons, and area E represents the amount of free carbon. It will be noted that all of the free carbon is shown in the pitch residue and that it therefore constitutes a larger percentage of the residue than of the crude tar. The effect of free carbon in refined tars is treated in Art. 28. It will be noted that the horizontal and inclined retort tars show a much higher percentage of free carbon than does

the vertical retort tar. In all cases the percentage of saturated hydrocarbons is very small. The percentage of tar acids is largely dependent upon the amount of oxygen present in the coal from which the tar was produced but is also a function of the temperature of distillation and in all cases constitutes an appreciable proportion of the distillate. While these diagrams give a general idea of the relative characteristics of the three principal types of gas-house coal tars, the fact should not be lost sight of that the exact temperature and other conditions of distillation exert a marked influence upon tar produced from exactly the same coal. Thus two tars produced from the same coal and in the same type of retort but at different temperatures may vary greatly. From the horizontal gas-house retort as commonly fired, tars containing less than 20% free carbon are the exception rather than the rule. In the early days of the coal-gas industry, however, when high illuminating value of the coal gas itself was a prime requisite and enriching methods were not in vogue, the gas-house coal tars usually contained a very much lower percentage of free carbon and were of considerably lower gravity.

Coke-Oven Tars are those produced by the destructive distillation of bituminous coal in ovens or retorts designed primarily for the manufacture of large quantities of coke. Such ovens, which are constructed for the recovery of tar and other volatile constituents of the coal, are called by-product coke-ovens. There are many designs of coke-ovens, a number of which are in common use. At the close of 1913, 5688 by-product coke-ovens had been constructed and 504 were under construction. Of these ovens by far the largest number are the United Otto, Semet-Solvay, and Koppers types. Other types are known as the Otto-Hoffmann and the Didier ovens. By-product coke-ovens are very much larger than gas-house retorts. The original Semet-Solvay ovens were 30 ft long, about 16 in wide, and 5 ft 8 in high, with a charging capacity of over 4 tons of coal. The original Otto-Hoffmann ovens were somewhat larger and had a charging capacity of about 5½ tons. Many of the modern ovens are over 36 ft long, 26 in wide, and nearly 12 ft high, and have a charging capacity of from 12 to 16 tons of coal. These ovens are built of fire-clay brick and a number set together in a brick framework over a furnace. Because of the large charges of coal which they hold, the distillation process is slower than in gas manufacture, and as the main object is the production of coke, the temperature of distillation is usually kept lower than for gas manufacture. This results in the production of tars containing medium or low percentages of free carbon. The percentage of free carbon in the various types of coke-oven tars produced in the United States in

Table XIX —Free Carbon in Coke-Oven Tars of the United States

Type of Oven	Percent of Free Carbon		
	Minimum	Maximum	Average
Koppers	2.81	3.95	3.38
Semet-Solvay	4.04	9.00	6.74
United Otto	5.26	12.55	9.00
Otto-Hoffmann	8.62	14.69	12.16
Otto-Hoffmann and United Otto (mixed)	11.51	13.52	12.51
United Otto and Rothberg (mixed)	17.17	17.17	17.17

1911 are given in Table XIX. These figures are for the crude tars free from water.

The typical characteristics of an average coke-oven tar are shown in diagram in Fig. 17. The lettered areas in this diagram represent the same constituents as described for gas-house coal tars under Figs. 14, 15, and 16. In different coke-oven tars the relative proportions of constituents, of course, vary within certain limits as indicated by the percentage of free carbon in Table XIX. As compared with Fig. 14 it will be seen that in general coke-oven tars contain a somewhat lower percentage of pitch residue than do the horizontal gas-house retort tars. Owing to the very much lower percentage of free carbon (area E), however, the coke-oven tar really contains a higher percentage of heavy pitch bitumen as shown by area D. As the pitch bitumen constitutes the true cementing medium it is evident that a given quantity of refined coke-oven tar residue will go farther as a cementing medium than will the same quantity of refined horizontal gas-house retort tar. The inclined and vertical retort tars shown in Figs. 15 and 16 are similar to the coke-oven tars in this respect. It is seen that coke-oven tars like the gas-house tars contain but a small percentage of saturated hydrocarbons (area A) but are mainly composed of unsaturated hydrocarbons, the proportion of which in the distillate is shown by area B. Like the gas-house tars, they contain an appreciable quantity of tar acids (area C).

Water-Gas Tars are those produced by the cracking or destructive distillation of petroleum or petroleum products in the carburetion of water

Fig. 17. Coke-Oven Tar

Fig. 18. Water-Gas Tar

gas. They are thin, oily liquids usually having a specific gravity of between 1.000 and 1.100. They are produced in an atmosphere rich in hydrogen and carbon-monoxide and it is probable that the excess of hydrogen is partially responsible for some of the differences between water-gas tars and coal tars. One of these differences is a greater proportion of methyl derivatives of the unsaturated cyclic compounds which predominate in all tars. As the original oils contain little or no nitrogen and oxygen, nitrogen and oxygen derivatives of the hydrocarbons are almost entirely lacking in water-gas tars. For the same reason, crude water-gas tars do not contain ammoniacal liquor as an impurity. The sulphur derivatives may, however, occur as in the case of coal tars. The relative proportions of various constituents in a typical water-gas tar are shown diagramatically

in Fig. 18, which is directly comparable with Figs. 14 to 17 inc, showing four types of coal tars. As compared with the diagrams of the coal tars it will be noticed that the percentage of soft refined tar residue as indicated by the area below the line *a a* is considerably lower, amounting to about 57% against the 87% for the horizontal retort tar and 70% for the coke-oven tar. This is due to the higher percentage of volatile oils and very much lower percentage of free carbon. The free carbon, as shown by area E, constitutes about 1% of the refined tar residue and less than 1% of the entire tar. It is rare for crude water-gas tar to contain over 2% of free carbon, and sometimes less than 0.1% is present. This of course means a high percentage of heavy pitch bitumen as shown by area D, altho the total percentage of refined tar or pitch residue is comparatively low. The amount of saturated hydrocarbons, altho small as shown by area A, is found to be slightly greater than for the coal tars. This is not always true, however. In general, with a given type of gas oil, the more efficiently the carburetting process is run in the manufacture of water-gas the lower the yield of saturated hydrocarbons in the tar produced. This is explained by the fact that fractional distillation of the gas oil will yield comparatively high percentages of condensable saturated hydrocarbons; mild cracking less, and ultimate cracking or destructive distillation but little if any. It will be noticed that area C, the oxygenated hydrocarbons, is entirely lacking in the above diagram. This is one of the distinguishing characteristics of water-gas tar because of the absence of phenols and cresols or tar acids. The water-gas tar distillates are therefore almost entirely composed of unsaturated cyclic hydrocarbons.

Other Tars. Among the tars of minor importance may be mentioned BLAST-FURNACE TARS and OIL-GAS TARS. The former are sometimes recovered from blast furnaces in which coal is used as a fuel in the reduction of the ore. The production of blast-furnace tars is almost negligible as compared with the other types of tars which have been described. They are, however, members of the coal-tar family altho often quite different in character as they contain a much higher percentage of saturated hydrocarbons, and their specific gravity is much lower owing to the comparatively low temperature at which they are produced. Unlike the other tars, they may yield upon ignition as high as 5 to 7% ash due to the presence of fine mineral matter which is blown over into the condensers from the blast furnace. Oil-gas tars as distinguished from water-gas tars are produced in the manufacture of straight oil gas. There are a number of processes for producing illuminating gas directly from petroleum or petroleum products, all of which are dependent upon cracking the oil vapors in especially constructed retorts so as to form permanent gases of high illuminating value. Tar condensates are incidentally produced and in some of the processes the tar itself is again cracked for the production of more gas so that in the end little but hydrocarbon gases and free carbon or coke are produced. It is unlikely that either oil-gas tars or blast-furnace tars will ever be used to an appreciable extent for the manufacture of bituminous road and paving materials.

REFINED TARS

28. Distillation of Tars

Tar Stills. Stills for refining tars vary in size and shape fully as much as petroleum stills. They are constructed of steel and set in a brick framework, being protected from direct fire by means of a fire arch. The most

commonly used tar stills in Europe are vertical cylinders with a dome-shaped top and concave bottom as shown in Fig. 19. Their capacity is usually 2000 or 3000 gal. The top is provided with a manhole and an inlet pipe for charging. A large curved vapor pipe at the top of the dome leads the volatile products to a coil condenser. A draw-off pipe is located near the bottom and leads directly to a cooling tank or smothering chamber. The bottom of the tank is made concave to facilitate the distribution of heat thruout the charge. The still is provided with a thermometer pocket or opening near the top for thermometer or pyrometer. It is equipped with interior pipes branched and suitably perforated so that steam or air may be injected into the charge of tar during distillation and thus facilitate the removal of the heavier oils without recourse to unduly high temperatures. The condensing coil is placed in a large tank of water which may be kept cool for the condensation of the light volatile distillates and be warmed, if necessary, to prevent clogging with solid naphthalene if the tar distilled runs high in that constituent. The vertical type of still is used to a limited extent in the United States and is sometimes constructed with a convex instead of concave bottom. It may be either wholly or partly incased in brickwork. The general tendency in American practice, however, is to make use of long cylindrical horizontally set stills similar in general design to the commonly used petroleum still. The modern horizontal tar still averages about 10 000 gal capacity but sometimes runs as high as 20 000 gal. The details of construction are so similar to petroleum stills which have been described in Art. 19, that Fig. 8 may serve as a general illustration for both. The tar stills are fitted with devices for steam- or air-agitation and a by-pass is sometimes placed in the vapor line to deflect the flow of tar from the condenser should frothing occur, as the tar refiner is even more seriously bothered by the presence of water in the product distilled than is the petroleum refiner. This by-pass leads to a spue tank which is capable of holding the entire contents of a still if necessary. The stills are placed in the open and a number are often set in a single brick framework to form a battery. The modern condensers are of similar design to those used in connection with petroleum stills but often discharge into deep narrow rectangular tanks or pans which are allowed to fill until the total distillate which they contain shows the gravity at which a cut is to be made. The pan is then discharged into the proper storage tank. The stills are fitted with small draw-off pipes thru which samples of the residuum may be taken and tested during the distillation process. A large draw-off leads to the cooler or smothering chamber so that at the end of a distillation the charge of residuum may be run off by gravity or, if the still is at a lower elevation than the cooler, it may be forced over by steam or air pressure. The coolers are large iron tanks exposed on all sides so as to obtain as quick cooling as possible. The cooling, however, often requires a long time before it is safe to run the residual into open barrels. In some cases the coolers are provided with steam coils so as to keep the residual at any desired temperature for further handling. The coolers are provided with a weighed cover or automatic relief to take care of any explosion which may result from the presence of air in the cooler at the time the hot residue is run in.

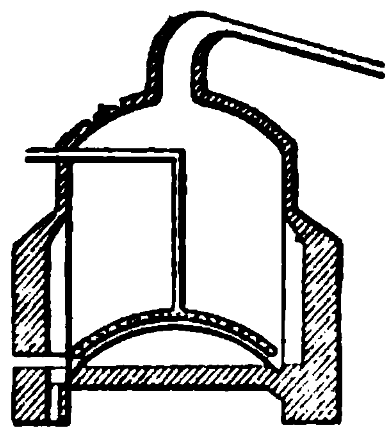


Fig. 19. Vertical Tar Still

For the softer residues which may be shipped in tank cars, recourse is often had to air or steam pressure as a means of transporting them thru pipe lines, which are sometimes steam jacketed in order to prevent possible clogging by too rapid cooling of the tar. By means of these lines the refined tar may, if desired, be blown directly from the still to the tank car or tank wagon.

Tar Refining. As it is practically impossible to remove all water from crude tars by sedimentation, they are sometimes run thru special dehydrating devices before charging them into the still (see Art. 9, DEHYDRATION. The water may be removed by distillation but it is a slow and expensive process, as great care has to be exercised to prevent foaming and a long time is required to coax the water off without bringing with it the entire contents of the still. This is particularly true of high carbon tars in which the free carbon appears to tenaciously retain the water. Moreover, the specific heat of the tar is only about 0.3 or 0.4 so that much extra heat is required to remove the water by distillation. Dehydrating devices, however, usually leave a small amount of water in the tar and considerable trouble is experienced from even this small quantity which may amount to only a few tenths of one per cent. After charging, the contents of the still are carefully heated until the vapor temperature is about 105° or 110° C, (221° or 230° F) when all the water has passed off with the light distillate. This point is usually indicated by the cessation of a peculiar noise within the still, known as the rattles, which occurs as the last of the water is being removed and is produced by condensation of the water at the top of the still, from which it falls back into the more highly heated residuum, thus causing a series of small explosions as it is suddenly converted into steam again. After all water has been removed distillation proceeds quietly and without trouble provided steam or air agitation is used. This is particularly necessary in the case of tars containing a high percentage of free carbon, owing to the tendency of the carbon to deposit on the bottom of the still and produce a heavy coating of coke. Agitation with air does not produce as pronounced an effect with tars as with petroleums, there being but little chemical reaction induced between the oxygen of the air and the tar hydrocarbons at the temperature of distillation. The exact method and extent of distillation depend upon just what products the tar refiner is primarily working for. In most cases the tar producer does not distill his own tar but sells it to the refiner, who may purchase from a great many sources of supply. When this is the case the tar refiner often has a variety of tars of different characteristics upon which to work and the selection or blending of two or more tars before distillation is fully as important as the method and extent of distillation when it is desired to produce refined products having given characteristics. In the preparation of refined chemicals such as drugs and dyes, of which there are an immense number, from tar distillates, the European countries are far in advance of the United States. This is particularly true of Germany, which country disposes of large quantities of tar products to the United States. As a result the European tar refiner often works primarily for quantity and quality of valuable distillate and in so doing distills his tar to a hard brittle pitch residue. In incidentally producing residues of any desired consistency, he then fluxes or cuts back the brittle residue with the least valuable distillate or distillate product which he has available. In other words, his residues are of secondary importance and their quality for use in highway engineering may suffer thereby. The American refiner, on the other hand, as a rule works

primarily for residues or refined tars and prepares comparatively few refined products from his distillates. This is shown by the fact that altho the production of crude tar in the United States is vastly more than sufficient to produce all of the refined chemical products which it consumes, it nevertheless annually imports millions of dollars' worth of such products but little or no residuals. This is shown by the following importation statistics for 1913 as given by Parker (32).

Table XX.—Coal-Tar Products Imported into the United States, 1913

Material	Value	Duty
Salicylic acid	$ 2 969	$ 613
Alizarin and other colors or dyes	1 493 840	Free
Aniline salts	323 420	4 034
Colors or dyes not specially provided for	7 253 788	2 176 136
Preparations not colors or dyes	702 721	131 268
Products not medicinal, such as benzol, etc	1 186 090	11 678
Total	$10 962 828	$2 323 729

The methods of American refiners in the manufacture of tar residuums are of particular interest from the standpoint of highway engineering and Fig. 20 serves to illustrate the general practice followed in the manufacture of straight residuals and certain crude distillates. As distillation proceeds the residue in the still becomes more and more viscous. Samples are withdrawn and tested from time to time until the desired consistency has been secured. In the case of quite fluid residuals viscosity tests are made. For the semi-solid and solid residues, the float and melting point tests are largely used. As in the case of petroleums, the residual, after being discharged from the still, is usually a finished product and requires no further treatment. For some purposes, however, cut-back products are manufactured, but in such cases the original distillation is seldom carried to the production of a hard brittle pitch residue. Residues of various consistency are generally sold as dust layers, carpeting mediums, cements for use in bituminous macadam construction and coarse aggregate bituminous concrete, and also as fillers. Distillates are only of interest

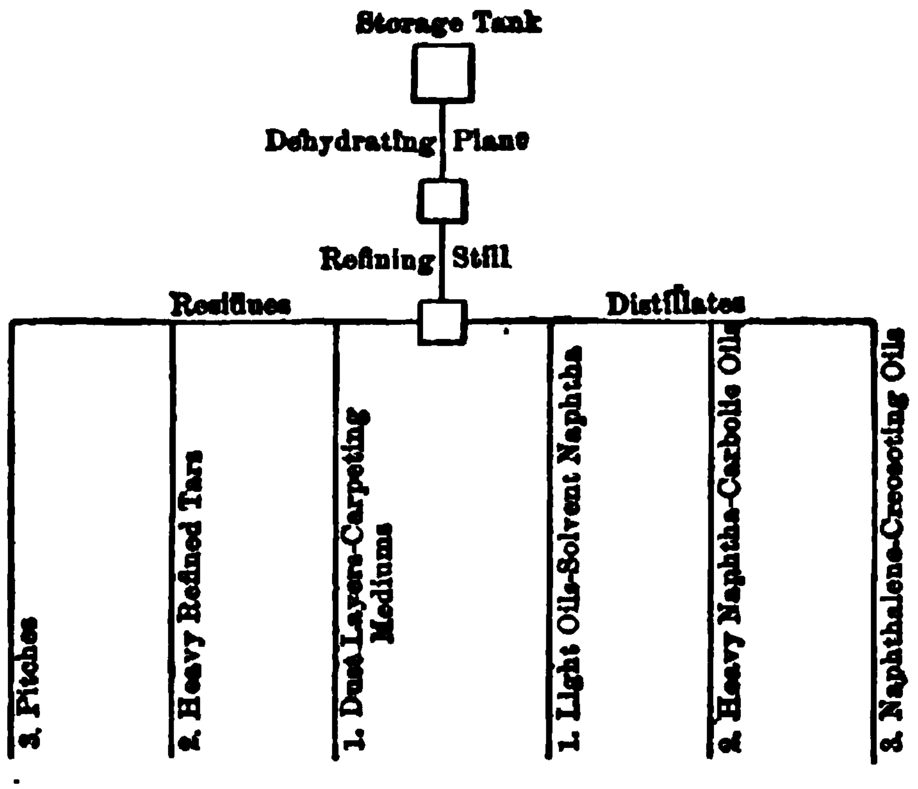


Fig. 20. Distillation of Tar

from the standpoint of highway engineering when used as creosoting oils for wood block and structural timber or when used for cutting back the tar residues. The lighter distillates are usually further refined by redistillation and acid purification for the production of various grades of benzol, toluol, solvent naphtha, etc. The next heavier distillates are often worked for the recovery of naphthalene, and in the case of coal tars for phenol or carbolic acid and cresols. Distillates for creosoting purposes are considered in the following subsection. None of the distillates are ordinarily used as dust layers as in the case of petroleums. In some cases either during or after distillation a relatively small amount of either fluid petroleum residuum or asphalt is combined with the tar residuum with which it readily fluxes. Such materials are then known as tar-asphalt products and if properly prepared may show certain desirable characteristics which would not be possessed by the straight distilled tar residue. For further details and principles governing distillation, see Art. 10.

Free Carbon in Tars exists in the form of finely divided amorphous black particles resembling soot or lampblack. These particles are held in suspension in the tar and will not readily settle out even if the tar is very fluid. They are insoluble in carbon disulphide and are therefore not bitumen. If filtered from the bitumen with the aid of this solvent the free carbon is found to be a dry black powder entirely lacking in cementitiousness. Ultimate analysis indicates that it is not, however, pure carbon but probably a mixture of hydrocarbons very rich in carbon, which have been produced by a very advanced stage of cracking of the vaporized hydrocarbons within the retort or superheater during the original formation of the tar. For all practical purposes, however, it may be considered as carbon and as an inert impurity in the tar bitumen. It is non-volatile at ordinary distilling temperatures and for this reason always remains in the residue of a tar distillation. It thus necessarily constitutes a larger proportion of any tar residue than of the original tar from which the residue was produced. As a very high percentage of free carbon is not considered desirable in refined tars commonly used in highway engineering, those crude tars which originally carry a high percentage of free carbon cannot well be utilized in the manufacture of such products unless mixed in suitable proportions with a low carbon crude tar prior to distillation. If both low and high carbon tars are available to the tar refiner, he is able by judicious mixing to obtain a combination which upon subsequent distillation will yield a refined tar containing less than the maximum limit of free carbon which has been set. Knowing the percent of distillate which will have to be removed in order to produce a residue of desired consistency, the percentage of free carbon in the refined tar may be closely approximated from the percentage present in the material distilled. If, however, the tar is badly cracked or locally overheated during distillation, additional free carbon will be formed. As all tars originally contain some free carbon, however, it is impossible from its determination in the finished product to determine whether or not cracking has taken place during distillation as in the case of petroleum products. While chemically inert, free carbon has a decided effect upon certain physical characteristics of the tar in which it occurs. It increases the gravity of a tar and also its viscosity or apparent consistency to a marked extent. It is quite possible to remove free carbon from a tar by passing it in a heated and fluid state thru a filter press. This process is not as a rule commercially possible in the manufacture of refined tars for use in highway engineering, but if carried out

the filtered tar is found to have a lower gravity and to be much more fluid than before filtration. This latter fact has a most important bearing on the proper selection and specification of refined tars containing a considerable amount of free carbon as the consistency of the actual tar bitumen is a most important consideration. In a general comparison of low and high carbon tars the following facts are of interest to the highway engineer. For refined tars of the same degree of hardness those of low free carbon contents have greater inherent binding strength than those of high carbon contents. In refined tars whose bitumen is of the same degree of hardness, those high in free carbon have a greater inherent binding strength than those low in free carbon, but the binding capacity of the former is lower because of the lower percentage of bitumen present. The waterproofing value of high carbon tars is in general less than that of low carbon tars. A high percentage of free carbon tends to retard absorption of the tar bitumen by porous surfaces. When a tar is exposed in comparatively thin films free carbon has little or no effect in retarding volatilization of the lighter bituminous constituents. In certain classes of tar aggregates free carbon may serve as a filler and add to the mechanical strength of the aggregate, but finely divided mineral matter, which may be incorporated in any desired amount, is more satisfactory in this connection. In general it is considered desirable that a tar dust layer should not contain over 8% free carbon, that a tar carpeting medium should not contain over 15% free carbon, and that for bituminous macadam and bituminous concrete construction a refined tar should not contain over 20% free carbon. There is, however, some difference of opinion in this connection.

Naphthalene in Tars. Naphthalene, $C_{10}H_8$, frequently occurs in tar in larger quantity than any other one hydrocarbon, and for this reason it exerts an appreciable influence upon the physical and chemical properties of the tar. In the pure state it exists in white flakey crystals or scales melting at 79° C (174° F) and having a boiling point of 218° C (424° F). It has a characteristic odor commonly familiar in moth balls and is extremely volatile. It volatilizes far below its boiling point and from crude tars distills to a considerable extent with the aqueous vapors and also with the light tar oils. Even at ordinary temperatures it volatilizes slowly from both crude tars and refined tars in which it is present. No satisfactory method has as yet been devised for its quantitative determination in tars, but its presence in appreciable quantities is readily detected by its crystallization from certain fractions obtained by distilling the tar. In some tars it occurs to such a large extent that almost the entire distillate solidifies or crystallizes upon cooling. In the manufacture of straight residual refined tars for use in highway engineering some of the naphthalene is removed during distillation. A considerable proportion, however, usually remains behind in the residue. The presence of this naphthalene exerts a marked influence upon the consistency of the tar, and as it is a volatile constituent its effect in this connection is of considerable interest. From its nature it cannot be considered as a binding constituent, but, altho it is solid, it may combine with and serve as a flux for those hydrocarbons which are directly responsible for the cementitiousness of tars. Thus by heating together a quantity of naphthalene and a hard tar pitch, it is possible to produce a soft and almost fluid product. In this connection it has been found that the fluxing value of naphthalene for hard tar pitches is somewhat greater, altho quite similar to the heavier tar distillates free from naphthalene or other crystallizable solids. This is true until the mixture becomes so sat-

urated as to cause the naphthalene to precipitate. For the harder tar pitches the addition of very small percentages of naphthalene produces a more marked increase in fluidity than for originally softer pitches. On the other hand, where naphthalene is present beyond its point of saturation, it decreases the fluidity of the product at temperatures below its melting point but at higher temperatures it continues to increase the fluidity of the product. The conclusions to be drawn from the above facts are that refined tars containing a high percentage of naphthalene, altho the lighter tar oils may be absent, may be expected to harden rapidly upon exposure thru loss of the naphthalene by volatilization. This is particularly true when the refined tar is used for surface treatment. Naphthalene may be entirely eliminated from a tar by distillation to a hard pitch residue and cutting-back such residue to desired consistency with a heavy non-volatile naphthalene free tar distillate, but this practice is seldom followed in American refineries. Where rapid hardening after use is not desired, as in the case of refined tars for bituminous concrete construction, a low naphthalene tar is preferable to one containing a high percentage of naphthalene.

29. Refined Tar Products

Crude and Residual Tar Dust Layers. Crude tars are sometimes used as dust layers. The majority of crude coal tars are, however, too viscous for successful cold application and have to be combined with distillates or very fluid tars in order to make them applicable for such use. Water-gas tars and some coke-oven tars may be applied cold in their crude or partially dehydrated state. It is customary, however, to subject tars to some process of refinement before marketing them. High carbon tars are totally unsuited for use as dust layers. The majority of tar dust layers are therefore manufactured from low carbon crudes. In order to so use tars containing as high as 5% free carbon, it is not unusual to have them combined with a small amount of water, which increases their fluidity. Partly dehydrated coke-oven tars combined with water-gas tars may be made to serve this purpose. As crude water-gas tars are very fluid and contain a low percentage of free carbon, they may be distilled to remove their more volatile oils without increasing their viscosity to such an extent that cold application is impossible. Semisolid residual tars may also be fluxed or cutback with a large amount of tar distillate to produce dust layers. Refined tars are also emulsified in some cases in much the same way as petroleums (see Art. 21) for use in dust laying. Tar emulsions have not, however, been used in the United States to any extent. The tar refiner usually has so many different types and grades of tars which he can blend to produce the product he wishes to manufacture that it is often a difficult matter to identify the origin of a manufactured product. The primary function of tar dust layers is identical with that of petroleum dust layers. Owing to the fact that they tend to volatilize and harden more rapidly, however, their excessive use is not as serious a matter as is the case with the petroleum dust layers. They should be sufficiently fluid to apply cold by means of a pressure distributor at a rate of not over ¼ gal per sq yd. Their repeated use may result in the formation of a thin, comparatively hard superficial coat or bituminous carpet. They are often used to advantage in the surface treatment of an old bituminous macadam, as they tend to enrich the seal coat and prolong its life. They are black in color and usually have a strong odor of light oils and naphthalene.. The analyses on opposite page are typical of tar dust layers. The first analysis is that

of a dust layer produced from a water-gas tar by distillation of the more volatile constituents. The second is of one produced from a low carbon coal tar and shows the presence of both water and light oils. The water is largely responsible for the low specific viscosity of this material as compared with the first sample, altho its precentage of pitch residue or heavy tar hydrocarbons is higher. Its specific gravity and percentage of free carbon indicate a coke-oven tar.

Table XXI —Tar Dust Layers

	(1)	(2)
Specific gravity 25°/25° C (77°/77° F)	1.120	1.149
Specific viscosity (Engler) 50 cu cm, 40° C (104° F)	14.0	10.9
Soluble in CS_2 (total bitumen)	99.05%	95.05%
Organic matter insoluble (free carbon)	0.90%	4.89%
Inorganic matter insoluble (ash)	0.05%	0.06%
	100.00%	100.00%
Distillation percent by volume:		
Water	0.0%	1.7%
Oil distillate to 110° C	0.0%	0.9%
Distillate 110° to 170° C	0.7%	2.5%
Distillate 170° to 270° C	23.7%	18.4%
Distillate 270° to 300° C	13.1%	4.6%
Pitch residue above 300° C	62.5%	71.9%
	100.0%	100.0%

Refined Tar Carpeting Mediums are usually straight distilled residual tars too viscous to apply cold. When heated, however, they should become sufficiently fluid to apply uniformly over a road surface by means of a pressure distributor at the rate of not over ½ gal per sq yd. They ordinarily possess considerable cementitiousness and harden rather rapidly after application as compared with the residual carpeting mediums prepared from petroleum. Like other carpeting mediums, their function is first of all to adhere to the road surface and then hold in place the covering of fine aggregate with which they should combine to form a bituminous carpet. If used in excess they are apt to produce a mechanically unstable carpet owing to their original soft consistency. Applied at the proper rate they harden sufficeintly after application to produce a stable carpet. The initial hardening which is desirable is apt to continue, however, until the carpet becomes so hard as to wear away rather rapidly under traffic. This is particularly true of those products which contain a high percentage of the lighter oils or an excess of naphthalene or free carbon. For carpet work, this general tendency to harden even too much is preferable to not hardening sufficiently. The very qualities which make residual tars suitable as carpeting mediums make them less desirable for seal coat work on bituminous macadam or bituminous concrete pavements. For such purpose a harder bituminous material is preferable as it will adhere to the newly laid bituminous concrete and can be used of originally desirable consistency. Seal coats should therefore harden as little as possible after use. In some cases petroleum or asphalt products are combined in relatively small proportion, usually not over 15%, with tar carpeting mediums in order to reduce the tendency to harden too much. The characteristics

of two typical tar carpeting mediums are shown in Table XXII. The first material is a tar-asphalt preparation as evidenced by the dimethyl sulphate test, and has been prepared from a water-gas tar. The second material is a coal-tar product as shown by the relatively high percentage of free carbon which, however, is not excessive. It contains no petroleum or asphalt product as shown by the dimethyl sulphate test.

Table XXII.—Tar Carpeting Mediums

	(1)	(2)
Specific gravity 25°/25° C (77°/77° F)	1.158	1.210
Float test at 50° C (122° F)	85 sec	45 sec
Soluble in CS_2 (total bitumen)	98.50%	85.05%
Organic matter insoluble (free carbon)	1.45%	14.93%
Inorganic matter (ash)	0.05%	0.02%
	100.00%	100.00%
Distillation percent by volume:		
Water	0.0 %	0.0 %
Distillate to 110° C	0.0 %	0.0 %
Distillate 110° to 170° C	0.3*%	0.0 %
Distillate 170° to 270° C	6.8*%	14.5†%
Distillate 270° to 300° C	17.9*%	8.0‡%
Pitch residue above 300° C	75.0 %	77.5 %
	100.0%	100.0%
Melting point of pitch residue	65° C (149° F)	74° C (165° F)
Dimethyl sulphate test on fraction above 300° C	part insoluble	all soluble

* Distillate free from precipitated naphthalene.
† Distillate contained about three-fourths its volume precipitated naphthalene.
‡ Distillate practically solid.

From the above results it will be seen that altho the second material is originally softer or shows a lower float test than the first, its tendency is to harden much more rapidly owing to the higher percentage of distillate to 170° C (338° F) and the presence of a large amount of naphthalene.

Bituminous Cements from Tars. Because of their tendency to harden after use and their susceptibility to temperature changes, the residual tars used in bituminous macadam and bituminous concrete pavements are usually much softer than either the residual petroleums or fluxed native asphalts used in the same types of construction. This is admissible when the aggregate is coarse because of the high cementitiousness of the soft semisolid tar residues. For fine aggregates where mechanical stability is dependent upon the hardness of the bituminous cement, tars are not generally used except perhaps for sidewalk construction. For the coarser aggregate pavements the same grade of tar used in the construction of the wearing course proper is also commonly used as a seal coat. Altho such a seal coat is apt to harden more rapidly than desirable in the case of the bituminous macadam, the underlying thick films of tar tend to enrich and prolong the life of the seal coat. In bituminous concrete construction, however, there is not the same excess of bitumen in the underlying course and for this reason an asphalt seal coat is sometimes employed when a refined tar is

used in the concrete proper. The characteristics of bituminous cements prepared from a water-gas tar, a coke-oven tar and a gas-house coal tar are shown in Table XXIII. Altho these tars are of similar consistency, as shown by the float test, it will be noted that, as in the case of crude tars, the residual water-gas tar shows the lowest percentage of free carbon and the residual gas-house coal tar the highest. The specific gravity of these tars increases with the percentage of free carbon. All of the materials show

Table XXIII.—Bituminous Cements from Various Tars

Tar	Water-Gas	Coke-Oven	Gas-House
Specific gravity 25°/25° C (77°/77° F)	1.172	1.215	1.258
Float test at 50° C (122° F)	158 sec	140 sec	170 sec
Soluble in CS_2 (total bitumen)	99.12%	86.60%	70.37%
Organic matter insoluble (free carbon)	0.83%	13.38%	29.60%
Inorganic matter insoluble (ash)	0.05%	0.02%	0.03%
	100.00%	100.00%	100.00%
Distillation percent by volume:			
Water	0.0 %	0.0 %	0.0 %
Distillate to 110° C	0.0 %	0.0 %	0.0 %
Distillate 110° to 170° C	0.7 %	0.3 %	0.0 %
Distillate 170° to 270° C	6.2 %	5.4 %	9.4 %
Distillate 270° to 300° C	16.0 %	12.9 %	6.5 %
Pitch residue above 300° C	77.1 %	81.4 %	84.1 %
	100.0 %	100.0 %	100.0 %
Melting point of pitch residue	65° C (149° F)	71° C (160° F)	85° C (185° F)

a very low percentage of ash, and the percentage of total bitumen is therefore almost entirely dependent upon the amount of free carbon present. All of the residuals have been prepared at sufficiently high temperatures to remove the more volatile oils as shown by the results of distillation. The relation of total distillate to pitch residue is found to vary somewhat but the ratio of total distillate to actual bitumen in the pitch residue will, upon calculation, be found to be nearly the same. Pitch fillers for stone and block pavements are manufactured from tars by distilling and blowing the residue to the desired melting point. They are often quite hard and brittle and contain a high percentage of free carbon, show a high specific gravity and a melting point of 45° C (113° F) or higher. They are much more susceptible to temperature changes than are the blown petroleum or asphalt products prepared for the same purpose.

CREOSOTING OILS

30. Manufacture of Creosoting Oils

Classification of Creosoting Oils. The term creosote was originally applied to certain constituents of wood tar. Later it was extended to cover the oxygenated hydrocarbons or cresols found in the distillates of coal tar. Those distillates, particularly the heavy distillates rich in oxygenated hydrocarbons, were then known as creosote oils. Creosote oils from coal tar

have for many years been extensively used to impregnate wood for structural uses, the process of impregnating being known as creosoting. The term creosoting oil is now commonly applied not only to the creosote distillate oil but to a variety of other bituminous materials which are used to impregnate wood. Creosoting oils are of particular interest in highway engineering with regard to the impregnation of wood paving block. Their use in this connection dates back to a pavement laid at Galveston, Texas, in 1873. Creosoting oils which are used in the preservation of wood blocks may be classified as (1) heavy distillates of coal tars and water-gas tars; and (2) residual tars and oils containing tar residues. Petroleum oils have also been used to a limited extent in the impregnation of wood for structural purposes.

Preparation of Creosoting Oils. Distillate creosoting oils are obtained mainly from coal tars but also from water-gas tars by the process of fractional distillation such as described in Art. 28. They vary considerably according to the cuts made during distillation and the character of tar distilled. During distillation of the crude tar a cut is usually made after the removal of practically all oils boiling as high as 170° C (338° F). The heavier oils then begin to distill and the creosoting oil may consist of the entire distillate obtained during the remainder of the distillation process. It is evident that the extent to which distillation is carried will materially affect the characteristic of the creosoting oil produced by this means from a given tar. Sometimes the heavy distillates from a number of distillations of different tars will be mixed together to produce the creosoting oil. Two types of tar may also be mixed prior to distillation and thus produce a creosoting oil of somewhat different character than would have been produced by the distillation of either alone. Sometimes intermediate cuts or fractions may be made during distillation and certain of these fractions worked for the recovery of desirable constituents such as naphthalene, anthracene, etc, after which the remaining oils are run back with the rest of the creosoting oil distillate. The second class of creosoting oils mentioned in the preceding paragraph may be prepared in a variety of ways. Where very fluid crude tars are available, such as water-gas tars and certain coke-oven tars, they may be distilled for the removal of water and some of the lighter oils and the residues still be sufficiently fluid to use as creosoting oil. If too viscous they may be thinned to the desired degree of fluidity with a small amount of heavy oil obtained from another distillation. In the case of low carbon tars distillation may be carried to the formation of a pitch residue and the pitch then fluxed with a large amount of heavy tar distillate to produce a creosoting oil. Creosoting oils containing residual products may therefore be either straight fluid residues or mixtures of oils and residues.

31. Characteristics of Creosoting Oils

Function and General Characteristics. In the manufacture of creosoted wood block, creosoting oils are ordinarily used in connection with the impregnation of southern yellow pine, Norway pine, Douglas fir, or tamarack. The oils should be sufficiently fluid to manipulate properly and at the temperature of impregnation, somewhat under 121° C (240° F), should suffer no chemical change or decomposition. They should adequately waterproof the block when present to the extent of from 14 to 20 lb per cu ft. They should preferably be as slightly volatile as possible under the conditions to which the block is subjected, and when used to the extent

necessary for waterproofing should not ooze out of the wood or bleed in warm weather. They should in addition possess sufficient antiseptic properties to prevent decay of the wood from the action of fungus or other growth. Their permanent waterproofing value is perhaps the most important consideration in so far as the life of the pavement is concerned and this is of course dependent to some extent upon their tendency to remain in the wood and not volatilize.

Tar Distillate Oils have been more extensively used in the treatment of wood block than have the oils containing tar residues. A large proportion of the distillate oils used in the United States is imported from Europe. They differ in certain respects from the average American oil. Considerably over 60 000 000 gal of creosoting oils are annually consumed by the United States. The importation of creosoting oil to the United States, as shown by statistics of the Census Bureau, was as follows for the fiscal years 1910 to 1914 inclusive, ending June 30.:

1910	36 719 782 gal
1911	45 499 838 gal
1912	50 319 736 gal
1913	63 997 602 gal
1914	59 271 677 gal

The characteristics of typical domestic and foreign distilled oils available in large quantities, as given by Forrest (20b), are shown in Table XXIV.

Table XXIV.—Distilled Creosoting Oils

Type	Domestic	Foreign	Coke-Oven
Specific gravity 15.5° C (60° F)	1.08	1.04	1.09
Free carbon	0.0 %	0.0 %	0.0 %
Tarry matter	1.3 %	0.7 %	10.0 %
Tar acids	7.0 %	13.6 %	trace
Solid naphthalene	....	18.0 %	....
Distillation:			
Distillate to 170° C	0.42%	0.70%	1.60%
Distillate 170° to 205° C	4.50%	1.50%	2.40%
Distillate 205° to 235° C	51.95%	35.20%	19.80%
Distillate 235° to 270° C	22.01%	32.60%	15.20%
Distillate 270° to 315° C	10.99%	20.00%	11.60%
Residue above 315° C	10.13%	10.00%	49.40%
	100.00%	100.00%	100.00%
Character of residue	soft	soft	soft
Insoluble in dimethyl sulphate	0.0 %	0.0 %	0.0 %
Paraffin scale	0.0 %	0.0 %	0.0 %

It will be seen that all of the distilled oils have a gravity somewhat greater than one. They may or may not carry a high percentage of naphthalene. Both naphthalene and the tar acids are quite volatile constituents, and from this standpoint are undesirable if present in excessive amounts. None of the oils contains free carbon as they are fractional distillates. The absence of petroleum products is shown by the absence of paraffin scale and material insoluble in dimethyl sulphate. All three oils yield but little distillate below 205° C (401° F). The percent of residue above 315° C (599° F) is shown to be much higher for the coke-oven tar oil than for the other two. This varies markedly, however, in different oils produced from the same tar, according to the extent of the original tar distillation. For an oil distilled from a given tar the percent of residue above 315° C (599° F)

usually increases with the specific gravity but this is not necessarily so for oils produced from different tars, as shown by the following analyses of a coal tar distillate creosote and a water-gas tar distillate creosote as given by Forrest (20*b*).

Table XXV.—Coal Tar and Water-Gas Tar Creosote Oils

Type	Coal Tar	Water-Gas Tar
Specific gravity 15.5° C (60° F)	1.098	1.072
Distillate to 235° C	15.0%	1.5%
Distillate 235° to 315° C	29.0%	15.0%
Residue above 315° C	56.0%	83.5%
	100.0%	100.0%

Creosoting Oils Containing Tar Residues are almost invariably heavier than the pure distillate oils and may usually be distinguished from the former by the presence of free carbon and the production of a hard pitch residue when distilled to 315° C (599° F). As an excessive amount of free carbon tends to prevent proper impregnation of the wood, only low carbon tar residues can be present to any considerable extent in this class of creosoting oils. The characteristics of typical creosoting oils containing tar residues which are available in large quantities, as given by Forrest (20a), are shown in Table XXVI.

Table XXVI.—Creosoting Oils Containing Tar Residues

Type	From Coke-Oven Tar	From Water-Gas Tar
Specific gravity 15.5° C (60° F)	1.16	1.13
Free carbon	5.3 %	0.6 %
Tarry matter	58.0 %	51.0 %
Tar acids	trace	0.0 %
Distillation:		
Distillate to 170° C	0.60%	0.50%
Distillate 170° to 205° C	0.90%	0.50%
Distillate 205° to 235° C	6.90%	1.70%
Distillate 235° to 270° C	11.40%	9.90%
Distillate 270° to 315° C	7.90%	15.00%
Residue above 315° C	72.30%	72.40%
	100.00%	100.00%
Character of residue	hard	hard
Insoluble in dimethyl sulphate	0.0 %	0.0 %
Paraffin scale	0.0 %	0.0 %

As compared with the distillate creosoting oils it will be noted that those containing tar residues are much less volatile. Owing to the presence of tar residue they are better waterproofing agents but more likely to bleed and produce a sticky surface in warm weather. All of the creosoting oils produced from tars have been found to be sufficiently antiseptic to prevent decay. There has been considerable prejudice on the part of engineers in favor of distillate oils which produce a cleaner and more attractive block than do those containing tar residues. As the latter are considerably cheaper, however, and offer certain advantages from the standpoint of durability and protection of the block from expansion caused

by undue water absorption, their rapidly increasing use is apparently assured.

TESTING BITUMINOUS MATERIALS

32. Conditions Governing Testing

Standard Methods. The testing of bituminous materials for use in highway engineering dates back to the early days of the sheet-asphalt paving industry. The original tests applied were a few crude physical tests which, while reasonably satisfactory for those experienced in the use of the then limited number of available materials, were not based upon sound scientific principles. The gradual increase in the number of materials available for highway engineering, the widely varying characteristics of different types and grades of these materials, and the many methods of treatment and construction in common use have necessitated an improvement and expansion of the older tests. A number of physical and chemical tests are now in use and much work has been done by chemists and engineers towards the standardization of the methods involved. More complete standardization is needed, however, in order to correlate and properly interpret the results of tests obtained by different laboratories and investigators. The methods described in this chapter are mainly limited to those in general use. Methods of chemical analysis which are not ordinarily used in routine testing have not been included. Most of the tests given are physical rather than purely chemical and are commonly indicated in specifications for bituminous materials.

Representative Samples. In order that tests shall truly show the characteristics of a large bulk of material it is, of course, necessary that each test shall be made upon a representative sample. Methods of obtaining such samples under different conditions are treated under Art 53. It may sometimes happen, however, that a sample received at the laboratory lacks uniformity due to segregation of the constituents during shipment or storage of the sample. This is particularly true of the more fluid bituminous materials which contain a considerable amount of impurities. In any event, thoro mixing of the sample is advisable before taking a portion for examination. Mixing frequently involves heating the material, in which case special care should be exercised to prevent loss of the lighter constituents by volatilization and consequent changes in certain characteristics. The same care should be exercised when the sample contains water and it becomes necessary to remove the water or dry the sample before making a test. The proper method of drying will depend to a great extent upon the nature of the material under examination. Evaporation of the water by placing the sample in an oven, distillation, application of a partial vacuum, desiccation over sulphuric acid, or other hygroscopic medium, natural gravimetric separation, and centrifuging are the methods most commonly employed for drying samples. After receiving a representative sample, care must be taken that it does not suffer change during the necessary manipulation prior to making an actual test.

Normal Temperature. As bituminous materials are often appreciably affected by very slight variations in temperature, the exact temperature at which a test is to be made is often specified. Normal temperature as applied to laboratory tests is taken at 25° C (77° F), which is considered as about average room temperature. Certain physical tests are almost invariably made at exactly 25° C (77° F) and, whenever the exact temperature of a test is not specified, it is understood that the temperature at

which it is to be made should preferably be at or near normal temperature, altho absolute regulation may not be necessary. The results of chemical tests are not so markedly affected by slight temperature changes as are the physical tests.

33. Specific Gravity

Basis of Determination. The specific gravity of most bituminous materials used in highway engineering is based upon the relative weights of equal volumes of the bituminous material and water at normal temperature and is usually expressed as Specific Gravity 25°/25° C (77°/77° F). As the weight of a given volume of almost every material varies at different temperatures, the temperature basis of comparison should always be indicated for very accurate work. A few bituminous materials, such as certain tar distillates, separate solid material, mostly naphthalene at 25° C (77° F), and as this makes it difficult to determine the specific gravity at that temperature, the determination is made at a temperature sufficiently high to insure complete fluidity. When this is done water at the same temperature or at 25° C (77° F) may be taken as unity. In either case the basis of comparison should be indicated. Thus, if the weight of a given volume of the material is obtained at X° C and compared with water at 25° C (77° F), the basis of comparison should be expressed as follows: Specific Gravity X° C / 25° C. An older temperature basis of comparison, which is still used to a considerable extent by manufacturers and also by the United States Government in the calibration of the volume of tank cars and other containers, is 15.5° C (60° F). If the coefficient of expansion of the material is known and the specific gravity basis of comparison is given, it is very easy to translate any given determination to terms of another basis of comparison (see Art. 34). Such a method is commonly employed by manufacturers who, for the sake of simplicity and rapidity, prefer to make use of a hydrometer in the case of many materials which have to be first rendered more fluid by the application of heat. In reporting the specific gravity of fluid bituminous materials it is not uncommon to express results to four places to the right of the decimal point. Three decimal places are usually reported in the case of semisolid and solid materials, owing to the fact that the limit of accuracy is exceeded beyond this point.

Hydrometer Method. Where a sufficient quantity of material is available the specific gravity of thin fluid bituminous materials may be conveniently determined by means of a hydrometer. The Baumé scale for liquids lighter than water is commonly used by petroleum refiners and many oil products are sold upon a Baumé degree basis. A double scale hydrometer graduated for both direct specific gravity and degrees Baumé is therefore most convenient. Such hydrometers may be obtained in sets, each individual instrument being scaled for direct gravity between the limits of one or two units in the first place to the right of the decimal. When double scale hydrometers are not available, the results obtained by one scale may be transposed to the other by one of the following formulas:

LIQUIDS LIGHTER THAN WATER: $\text{SP. GR.} = \dfrac{140}{130 + {}^\circ\text{B}}$ or $^\circ\text{B} = \dfrac{140}{\text{SP. GR.}} - 130$

LIQUIDS HEAVIER THAN WATER: $\text{SP. GR.} = \dfrac{145}{145 - {}^\circ\text{B}}$ or $^\circ\text{B} = 145 - \dfrac{145}{\text{SP. GR.}}$

It will be seen from these formulas that the same degree Baumé for the two scales does not indicate the same specific gravity. Thus in the scale

for liquids lighter than water, 10° B equal 1.000 specific gravity, while in the scale for liquids heavier than water 0° B equals 1.000 specific gravity and 10° B equal 1.0741 specific gravity. Most hydrometers are based upon the specific gravity at 15.5°/15.5° C. If the material tested is at 25° C it is evident that, without taking into account the coefficient of expansion of the hydrometer itself, the actual basis of comparison is then 25°/15.5° C. For all practical purposes this may be converted to the 25°/25° C basis by multiplying the reading obtained by the factor 1.002 which corrects for the decrease in weight of a unit volume of water raised from 15.5° to 25° C. Thus: Sp. Gr. 25°/25° C = Sp. Gr. 25°/15.5° C × 1.002. If the specific gravity is obtained at a considerably elevated temperature the coefficient of expansion of the hydrometer itself should be properly taken into account as well as that of water and the material examined. As the average hydrometer measures from 10 to 14 in in length, a cylindrical glass vessel or hydrometer jar about 14 in high and 2 in diameter makes a convenient receptacle for the material examined. When making the determination the material should first be brought to the desired temperature and the proper hydrometer then inserted. In case the hydrometer sinks slowly, owing to the viscosity of the material, it should be given sufficient time to come to a definite resting point, and this point should be checked by raising the hydrometer and allowing it to sink a second time. The hydrometer should never be pushed below the point at which it naturally comes to rest until the last reading has been made where the miniscus of the liquid cuts the scale. It may then be pushed below the reading for a distance of three or four of the small divisions of the scale, whereupon it should immediately begin to rise. If it fails to do so, the material is too viscous for the hydrometer method, and another method should be employed. Tables XXVII and XXVIII give the specific gravity equivalents of Baumé degrees for liquids lighter than water and liquids heavier than water.

Table XXVII. — Specific Gravities at $\frac{60°}{60°}$ F $\left(\frac{15.56°}{15.56°}\text{ C}\right)$ Corresponding to Degrees Baumé for Liquids Lighter than Water

Table XXVII. — Specific Gravities at $\frac{60°}{60°}$ F $\left(\frac{15.56°}{15.56°} \text{C}\right)$ Corresponding to Degrees Baumé for Liquids Lighter than Water—*Continued*

Table XXVII.—*Continued*

Degrees Baumé	Tenths of Degrees Baumé									
	0	1	2	3	4	5	6	7	8	9
90........	0.6364	0.6361	0.6358	0.6355	0.6352	0.6349	0.6346	0.6343	0.6341	0.6338
91........	.6335	.6332	.6329	6326	.6323	.6321	.6318	6315	.6312	.6309
92........	.6306	.6303	.6301	.6298	.6295	.6292	.6289	.6286	.6284	.6281
93........	.6278	.6275	6272	.6270	.6267	[illegible]	.6261	6258	.6256	.6253
94........	.6250	.6247	.6244	.6242	.6239	.6236	.6233	.6231	.6228	.6225
95........	.6222	.6219	6217	.6214	6211	.6208	.6206	.6203	.6200	.6197
96........	6195	.6192	.6189	.6186	.6184	.6181	.6178	.6176	6173	.6170
97........	.6167	.6165	.6162	.6159	.6157	.6154	.6151	.6148	.6146	.6143
98........	6140	.6138	.6135	.6132	.6130	.6127	.6124	.6122	.6119	.6116
99........	.6114	.6111	.6108	.6106	.6103	.6100	.6098	.6095	.6092	.6090
100........	.6087									

Table XXVIII.—Specific Gravities at $\frac{60°}{60°}$ F $\left(\frac{15.56°}{15.56°} C\right)$ Corresponding to Degrees Baumé for Liquids Heavier than Water

Table XXVIII.—*Continued*

A Westphal Balance (see Fig. 21) is convenient for quickly determining the specific gravity of comparatively small quantities of fluid bituminous materials, particularly fluid distillates. By using a vertical cylindrical container about ⅝ in diameter, it may be possible to use this instrument with as little as 15 cu cm of material. The determination is made by balancing a plummet in the liquid, the scale of the balance and the weights used being so designed as to give direct specific gravity readings. The Westphal balance is usually calibrated for 15.5°/15.5° C determinations and the results obtained are subject to the same corrections as noted under the HYDROMETER METHOD.

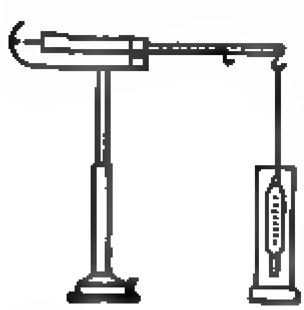


Fig. 21. Westphal Balance

Sprengle Tube. For determining the specific gravity of very small quantities of fluid materials the Sprengle or Nicholls tube, which is really a very small specially shaped pycnometer, is well

adapted. These instruments may be made with a capacity as low as 0.5 cu cm. The tube may be shaped as shown in Fig. 22, and may be conveniently suspended by a wire above the pan of an analytical balance. One arm of the tube is drawn out to a fine capillary opening. The other arm is somewhat larger but open and carries a mark to which the instrument is filled by sucking in the material thru the smaller arm. Any excess beyond the mark may be removed by means of a small piece of blotting paper. The instrument is first weighed empty, then filled to the mark with water at 25° C (77° F) and again weighed. It is then emptied, thoroly dried and filled to the mark with the material under examination. The weight of material divided by the weight of water gives the specific gravity.

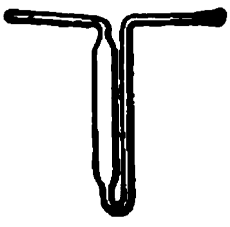


Fig. 22. Specific Gravity Tube

Pycnometer Methods. A pycnometer may be satisfactorily used for determining the specific gravity of both fluid and semisolid bituminous materials. One of special design such as shown in Fig. 23 is most convenient for general use as the ordinary narrow neck pycnometer is not well adapted for the viscous fluid and semisolid products. This instrument and its method of use, substantially as described by Hubbard and Reeve (25b) and recommended by the Spec. Com. Mat. Road Cons., Am. Soc. C. E. (13), is as follows: The pycnometer consists of a fairly heavy straight-walled glass tube, 70 mm long and 22 mm in diameter, ground to receive a solid glass stopper with a hole 1.6-mm bore in place of the usual capillary opening. The lower part of this stopper is made concave in order to allow all air bubbles to escape thru the bore. The depth of the cup-shaped depression is 4.8 mm at the center. The stoppered tube has a capacity of about 24 cu cm and when empty weighs about 28 g. Its principal advantages are (1) that any desired amount of bituminous materials may be poured in without touching the sides above the level desired; (2) it is easily cleaned; (3) on account of the 1.6-mm bore, the stopper can be more easily inserted when the tube is filled with a very viscous oil than if it contained a capillary opening. When working with semisolid bituminous materials which are too soft to be broken and handled in fragments, the following method of determining their specific gravity has been employed with good results. The clean, dry pycnometer is first weighed empty and this weight is called *a*. It is then filled in the usual manner with freshly distilled water at 25° C (77° F), and the weight is again taken and called *b*. A small amount of the bituminous material should be placed in a spoon and brought to a fluid condition by the gentle application of heat, with care that no loss by evaporation occurs. When sufficiently fluid, enough is poured into the dry pycnometer, which may also be warmed, to fill it about half full, without allowing the material to touch the sides of the tube above the desired level. When testing semisolid or solid materials, care should be taken in filling the pycnometer to avoid entrapping air. The tube and contents are then allowed to cool to room temperature, after which the tube is carefully weighed with the stopper. This weight is called *c*. Distilled water at 25° C (77° F) is then poured in until the pycnometer is full. After this the stopper is inserted, and the whole cooled to 25° C (77° F) by a 30-min immersion in a beaker of distilled water maintained at this temperature. All surplus moisture is then removed with a soft cloth, and the pycnometer and contents are weighed. This weight is called *d*. From the weights obtained

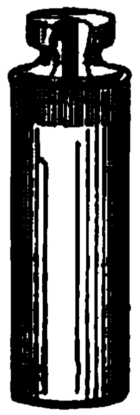


Fig. 23. Hubbard Pycnometer

the specific gravity of the bituminous material may be readily calculated by the following formula:

$$\text{SPECIFIC GRAVITY, } 25°/25° \text{ C } (77°/77° \text{ F}) = \frac{c - a}{(b - a) - (d - c)}$$

Both a and b are constants and need be determined but once. It is, therefore, necessary to make only two weighings for all determinations after the first. Results obtained according to the method given above are accurate to within 2 units in the third decimal place, while the open-tube method commonly employed is accurate to the second decimal place only. The specific gravity of fluid bituminous material may be determined in the ordinary manner with this pycnometer by completely filling it with the material and dividing the weight of the bituminous material thus obtained by that of the same volume of water.

Displacement Method. The specific gravity of bituminous materials which are sufficiently solid to handle in fragments at 25° C (77° F) may be determined by weighing a representative fragment in air and then in water at 25° C (77° F) If the determination is made upon an analytical balance, it is convenient to suspend a small fragment by means of a waxed silk thread from the hook on one of the pan supports, about 1½ in above the pan. Its weight is taken and called a. It is then weighed immersed in a beaker of water as shown in Fig. 24 and this weight called b. The specific gravity may then be calculated by means of the following formula:

$$\text{SPECIFIC GRAVITY} = \frac{a}{a - b}$$

This method is satisfactory for the determination of the specific gravity of compressed bituminous aggregates such as asphalt block and sections of sheet-asphalt or bituminous concrete pavement. In the case of coarse aggregates a much larger balance than the ordinary analytical balance may be required to weigh a representative sample.

Fig. 24. Displacement Method for Specific Gravity

Value of Specific Gravity Determinations. The specific gravity determination is commonly made upon all types and grades of bituminous materials with the exception of loose or uncompressed bituminous aggregates. It is one of the most valuable means of identifying a bituminous material and when considered in connection with other tests is often of service in determining the suitability of the material for a given use. In specifications it is used for both purposes and also for the sake of controlling uniformity of supply from a given source. In the examination of bituminous aggregates or sections of bituminous pavement it is of very material use in determining the degree of compression or percentage of voids which are present (see Art. 35), also the volume relations of bitumen and aggregates (see Art. 44). In general, bituminous materials tend to classify themselves according to specific gravity as shown by the following diagram which gives the approximate or average specific gravity limits of the more important types and grades. The pure bitumen of petroleum and asphalt products

in common use in highway engineering seldom exceeds 1.055 and of tars 1.18. A higher specific gravity therefore usually indicates the presence of mineral matter or heavy inorganic impurities. As many bituminous materials are purchased and used upon both a weight and a volume basis, the specific gravity determination is of use as a means of comparison. In this connection Fig. 26 shows the number of pounds per gallon and gallons per ton of materials having a specific gravity lying between 0.8 and 1.3. The further significance of the specific gravity determination will be considered in connection with other tests described in the following pages.

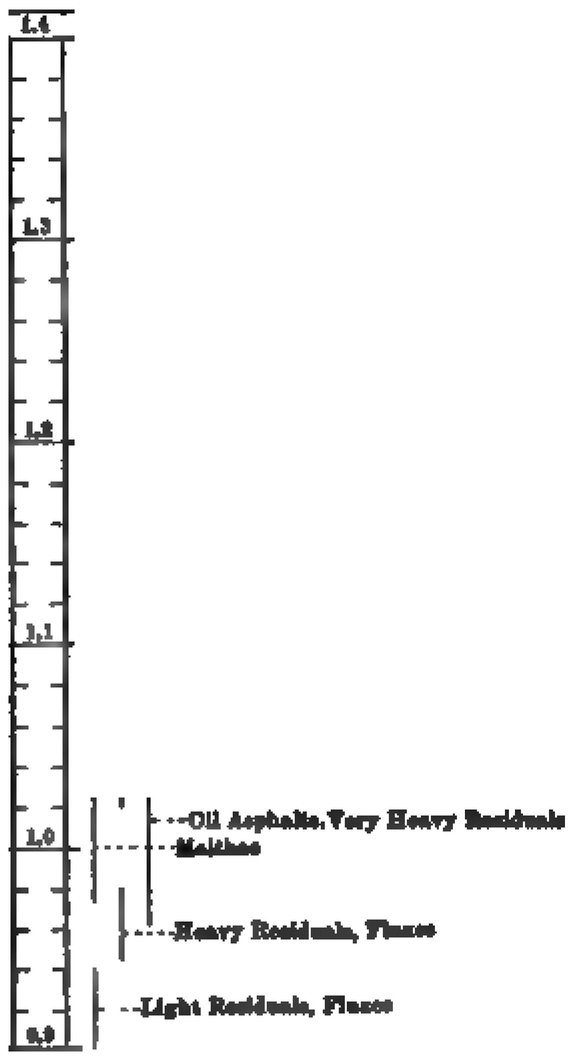


Fig. 26. Specific Gravity of Bituminous Materials

34. Coefficient of Expansion

Basis of Determination. The coefficient of volume or cubical expansion of any substance is the ratio between the increase in volume which it undergoes when its temperature is raised one degree and its original volume. The original or unit volume is set at some standard temperature. In the case of bituminous materials normal temperature, 25° C (77° F), is con-

venient to use, altho for the same reason that the specific gravity determination may be required at 15.5° C (60° F) this temperature is also sometimes taken as standard. The coefficient of expansion may be expressed either in terms of the Centigrade or Fahrenheit scale. If K represents the coefficient of expansion, then $K°\ C = 9K°\ F/5$ and $K°\ F = 5K°\ C/9$. The coefficient of expansion of most materials varies slightly at different temperatures and for this reason the volume change which is undergone between comparatively wide ranges of temperature is divided by the number of degrees of temperature and the average coefficient of expansion calculated. It is the average coefficient of expansion of bituminous materials which is of most interest from a practical standpoint. As a material ex-

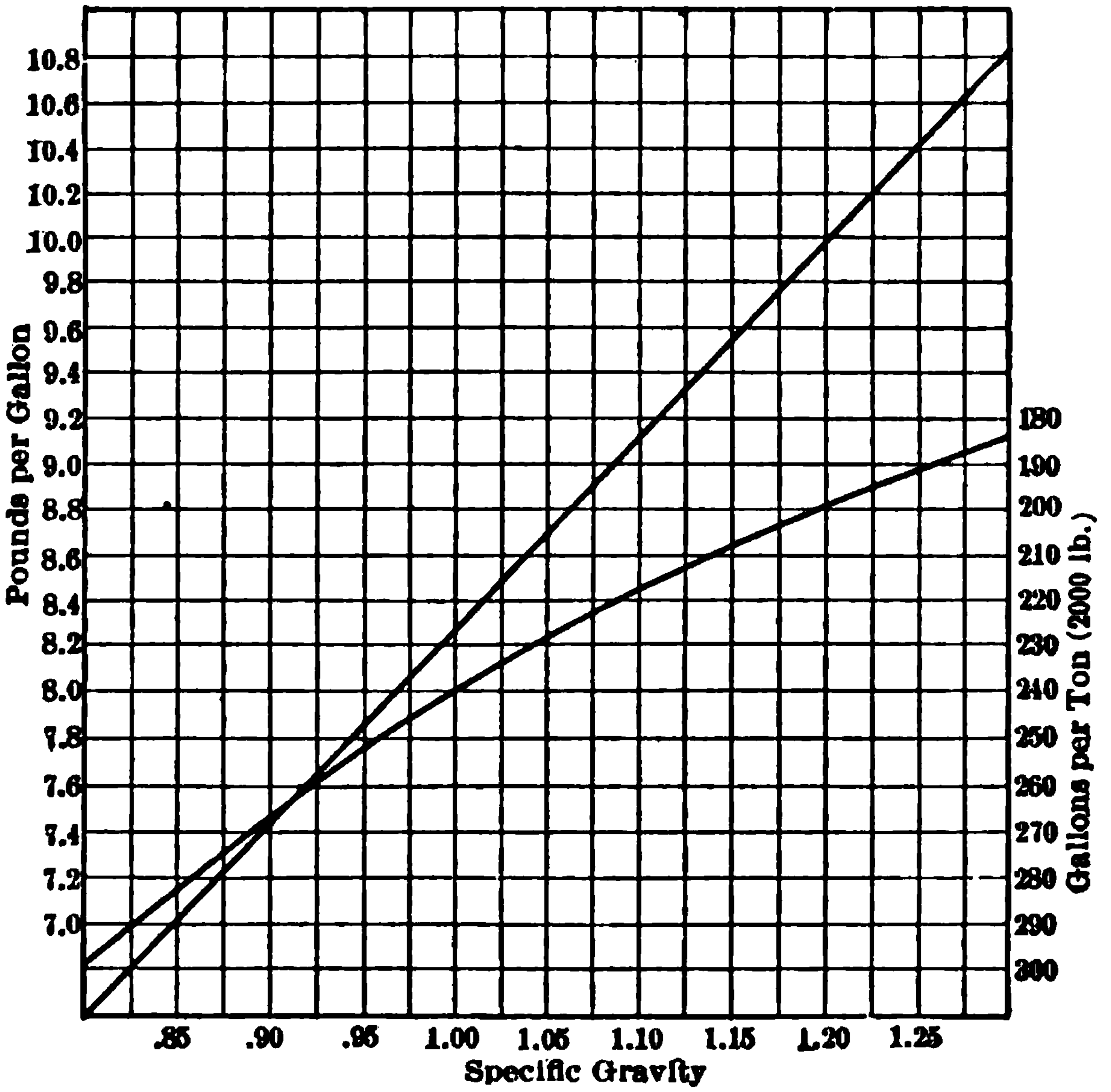


Fig. 26. Weight and Volume Relations

pands under the action of heat its specific gravity becomes less. It is thus possible to calculate K from volume measurements at different temperatures or from specific gravity determinations at different temperatures.

Volume Method. In the volume method of determining the coefficient of expansion, the bituminous material, in a fluid state, is poured into a glass receptacle known as a dilatometer, which consists of a large bulb with a long graduated narrow neck. This instrument is calibrated at normal temperature so that when filled to any mark on the graduated neck its contents are known. The determination is made by first bringing the dilatometer and contents to normal temperature and reading the position of the miniscus on the graduated neck. The instrument is then placed in

a carefully regulated oven and heated to any desired temperature. When its temperature is uniform the position of the miniscus is again read. The apparent volume at the elevated temperature is not the actual volume owing to the expansion which the instrument itself has undergone in acquiring the observed temperature. A correction has therefore to be made for the expansion of the glass, the cubical coefficient of expansion of which has been previously ascertained. The coefficient of expansion of the material is then determined by means of the following formula, where V represents the volume at normal temperature, V' the actual volume at the observed temperature, t normal temperature, and t' the observed temperature: $K = \frac{V' - V}{V\,(t' - t)}$. The volume method, while satisfactory for fluids, is not well adapted for use in connection with semisolid and solid bituminous materials and the specific gravity method is therefore to be preferred.

Specific Gravity Method. In the case of very viscous liquids, semisolids and solids, the pycnometer method as described in Art. 33 is first used to determine the specific gravity of the material at normal temperature. The weight of the water contents of the pycnometer at any desired elevated temperature is then obtained and another specific gravity determination made of the material at this elevated temperature as compared with water at the same temperature. From the known K of water, which is about 0.0002 per ° C, the specific gravity of the material at the elevated temperature is then determined as compared with water at normal temperature. The coefficient of expansion of the material is then determined by means of the following formula when G represents the specific gravity at normal temperature and G' represents the specific gravity on the same basis at the observed temperature: $K = \frac{G - G'}{G'\,(t' - t)}$.

Value of Coefficient of Expansion Determination. The practical value of the coefficient of expansion determination lies in its application to volume changes which take place upon heating bituminous materials, especially when the material is purchased or used upon a volume basis, which is often the case. In the vicinity of refineries, bituminous materials for hot surface application or bituminous macadam construction are not uncommonly delivered at the site of the work in tank wagons or tank cars at a temperature ready to apply. As the purchase price and rate of application are ordinarily based upon volumes at 15.5° C (60° F), it is necessary to know the coefficient of expansion of the material in order to compute the volume at such temperature. In some cases an arbitrary figure is mutually agreed upon. Thus for residual petroleums the coefficient of expansion is often assumed as 0.00072 per ° C (0.0004 per ° F), and in measuring hot oils a deduction of 0.72% is made for every 10° C above 15.5° C (0.4% for every 10° F above 60° F) which is commonly taken as standard temperature. The general formulas for finding volumes when K is known are as follows:

$$V = \frac{V'}{K\,(t' - t) + 1} \qquad V' = V\,[K\,(t' - t) + 1]$$

Based upon the arbitrary standard for oils above mentioned, Fig. 30 illustrates a convenient graphic method of showing (1) the number of gallons

at elevated temperatures represented by 100 gal at 15.5° C (60° F); and (2) the number of gallons at 15.5° C (60° F) represented by 100 gal at various elevated temperatures when the coefficient of expansion is 0.00072 per ° C (0.0004 per ° F). Comparatively little data is to be had relative to the coefficient of expansion of the various bituminous road and paving materials. In general, however, for a given type of material the coefficient of expansion decreases as the specific gravity increases. Thus the K of a crude petroleum or tar is greater than that of its residues and less than that of its distillates. From the data that is available it appears that the values of K, in Table XXIX, are reasonable averages for the types of materials listed. These figures are, however, only approximate and in certain cases are subject to considerable variation.

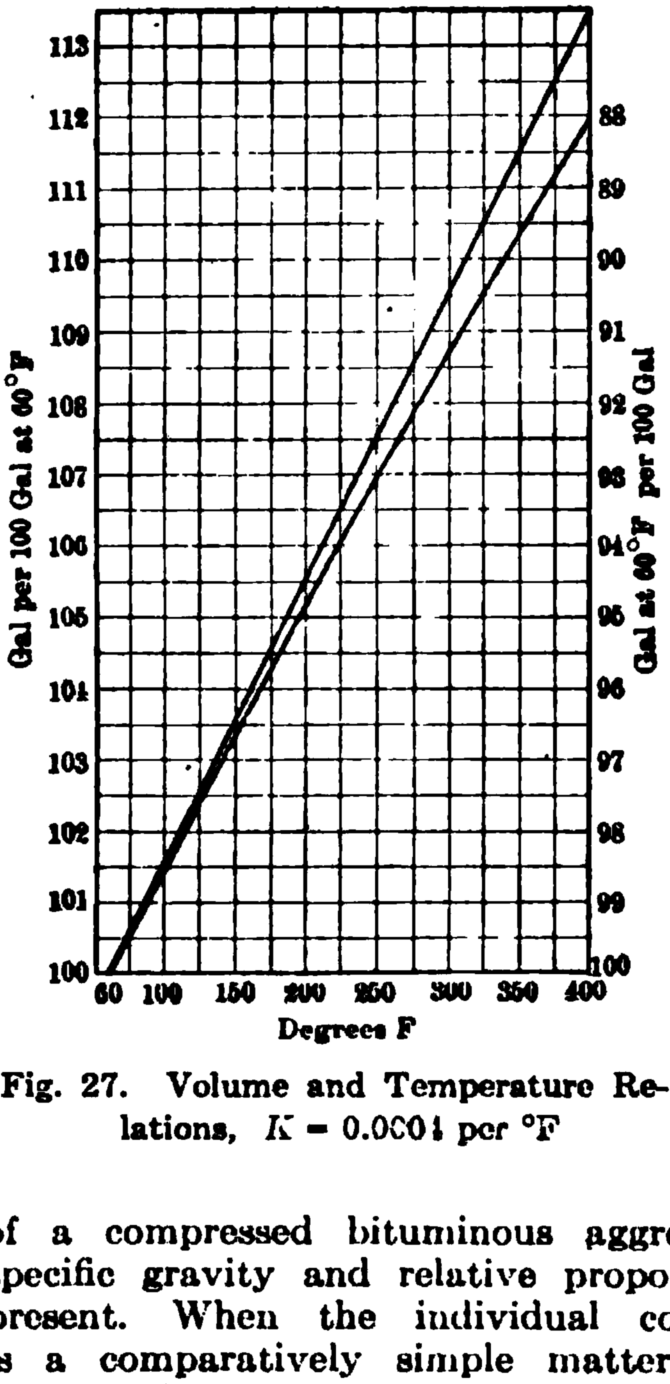


Fig. 27. Volume and Temperature Relations, $K = 0.0004$ per °F

35. The Density and Voids in Bituminous Aggregates

Theoretical Maximum Density of Compressed Bituminous Aggregates. Without reference to grading or practical possible compression, the theoretical maximum density of a compressed bituminous aggregate may be calculated from the specific gravity and relative proportions of the individual constituents present. When the individual constituents are at first hand this is a comparatively simple matter, but when a mixed aggregate or section of compressed pavement is under examination it is first necessary to remove and recover the bitumen, the percentage of which must also be determined (see Art. 44). The specific gravity of the recovered bitumen may then be determined by the pycnometer method as described in Art. 33 and that of the mineral aggregate by any of the well-known

Table XXIX.—Approximate Coefficients of Expansion of Bituminous Materials

Material	K per ° C	K per ° F
Gasoline	0.00090	0.00050
Creosoting oils	0.00080	0.00044
Fluid residual petroleums	0.00070	0.00039
Fluid tars	0.00060	0.00033
Asphalt cements	0.00055	0.00030
Heavy refined tars	0.00055	0.00030

methods for mineral particles. If coarse particles are present it is advisable to screen the aggregate into two or more sizes and determine the specific gravity of each. Thus a mixture of crushed rock and sand may be passed over a ¼-in screen. If all material retained on the screen then appears to be the same kind of stone the specific gravity of a single fragment is taken as representing the entire portion. The specific gravity of the entire finer portion may be determined by means of a Chatelier or Jackson apparatus, such as used in cement examination, or other similar method. After the gravity and percent by weight of the various constituents have been determined, their volume proportions are calculated by dividing their weight percentages by their respective specific gravities. The ratio of the sum of the weight proportions to the sum of the volume proportions is then the theoretical maximum density of the mix. When the percent by weight and specific gravity of two or three constituents are given, the following formula may be used if D represents the maximum possible density, W, W' and W^2 represent the percent by weight, and G, G' and G^2, their respective specific gravities.

TWO CONSTITUENTS

$$D = \frac{100}{W/G + W'/G'}$$

THREE CONSTITUENTS

$$D = \frac{100}{W/G + W'/G' + W^2/G^2}$$

The Probable Maximum Density of Compressed Bituminous Aggregates may be determined experimentally in the laboratory by heating the mixed aggregate to proper working temperature and compressing it in a cylindrical mold fitted with a plunger, which has also been heated to the same temperature. The plunger may be forced into the mold by means of a compression machine or heavy hammer. Upon cooling, the specimen is forced from the mold and its specific gravity determined by the ordinary displacement method. The probable maximum density is largely dependent upon the grading of the mineral particles, which is a most important consideration for fine aggregates. For a well graded fine aggregate carrying the proper percentage of bituminous cement, the probable maximum density should closely approach the theoretical maximum density.

The Actual Density of Compressed Bituminous Aggregates, such as a section of a bituminous concrete pavement, is directly determined by means of the displacement method (see Art. 33). If satisfactory compression has been obtained in the construction of the pavement its density should closely approach the probable maximum density as obtained by a laboratory test upon a section of the pavement which is first softened and disintegrated by warming and then compressed at proper working temperature, as described in the preceding paragraph.

Voids in Compressed Bituminous Aggregates. The percent of voids in a compressed bituminous aggregate is determined from the actual density of the compressed aggregate as compared with the theoretical maximum density which allows for no voids. Thus if D represents the theoretical maximum density and d the actual density, the percent of voids is determined by the following formula:

$$\text{PERCENT OF VOIDS} = \frac{100\,(D - d)}{D}$$

If proper compression has been secured in the construction of a bituminous concrete pavement, the percentage of voids as above determined should closely correspond with the voids in a properly prepared laboratory com-

pressed sample. If a fine aggregate is well graded and carries the proper percentage of bituminous cement, the voids should be very low and seldom over 3 or 4%.

36. Viscosity

Viscosimetry is the measurement of resistance to flow. In the natural movement of all liquids seeking a lower level or a level of less external pressure, internal friction is developed which tends to retard the flow. External friction is also developed between the liquid and the surrounding surface or substance. Both internal and external friction are therefore factors to be considered in the measurement of viscosity. The more common types of viscosimeters are based upon the principle of measuring the time of flow of a given quantity of liquid under a given head thru a given orifice. In such instruments it is evident that the relative retardation of flow caused by internal and external friction is largely dependent upon the size, shape and character of the orifice. For this reason the viscosity value obtained is more or less arbitrary. Liquid bituminous materials vary greatly in viscosity among themselves and the viscosity of a given material is greatly affected by the temperature of the material. In reporting the results of a viscosity test it is therefore important that all conditions of the test should be indicated or understood. The pressure or head, temperature and volume of liquid measured as passing the orifice are factors which may be controlled by the operator. As the orifices of different instruments of the same make are subject to unavoidable slight variations which affect the results of a test, it is customary to consider the viscosity of water for any given instrument as unity and to express the results of testing other liquids in terms of water as so-called specific viscosity. This tends to correct and place upon the same basis different instruments of the same make but it does not make the actual results obtained by different types of viscosimeters by any means the same. In expressing specific viscosities, it is therefore necessary to state the make or type of viscosimeter, of which there are several. While many of these instruments are admirably adapted for use in connection with certain liquids, none has yet been devised which really meets the requirements for successfully testing the wide range of liquid bituminous materials used in highway engineering. Of those which are available for this purpose, the Engler viscosimeter is, however, most generally used.

The Engler Viscosimeter, which is shown in Fig. 28, consists of a brass vessel *a*, with a cover *b*, for holding the material to be tested. To the conical bottom of *a* is fitted a conical outflow tube *c*, exactly 20 mm long, with a diameter on top of 2.9 mm and on the bottom of 2.8 mm. This tube can be closed and opened by the pointed hardwood stopper *d*. Pointed metal projections are placed on the inside of *a* at equal distances from the bottom and serve for measuring the charge of material, which is 240 cu cm. The thermometer *e* is used to ascertain the temperature of the material to be tested. The vessel *a* is surrounded by a brass jacket *f*, which holds the material used as a heating bath, either water or cottonseed oil, according to the temperature at which the test is to be made. A tripod *g* serves as a support for the apparatus and also carries a ring burner *h* by means of which the bath is directly heated. A measuring cylinder of 100 cu cm capacity, which is sufficiently accurate for work with road materials, is placed directly under the outlet tube. As all viscosity determinations should be compared with that of water at 25° C (77° F), the apparatus should

be previously calibrated as follows: The cup and outlet tube should first be scrupulously cleaned. A piece of soft tissue paper is convenient for cleaning the latter. The stopper is then inserted in the tube and the cup filled with water at 25° C (77° F) to the top of the projections. The measuring cylinder should be placed directly under the outflow tube so that the material, upon flowing out, will not touch the sides, and the stopper may then be removed. The time required both for 50 and 100 cu cm to run out should be ascertained by means of a stop-watch and the results so obtained should be checked a number of times. The time required for 50 cu cm of water should be about 11 sec, and for 100 cu cm about 22.8 sec. The use of the Engler viscosimeter in determining the viscosity of liquid bituminous materials at any desired temperature was recommended by the Spec. Com. Mat. Road Cons., Am. Soc. C. E. (13) as follows: "Bituminous materials shall be tested in the same manner as water, and the temperature at which the test is made shall be controlled by the bath. The material shall be brought to the desired temperature and maintained there for at least 3 min before making the test. The results are expressed as specific viscosity compared with water at 25° C (77° F), as follows:

Fig. 28. Engler Viscosimeter

$$\text{SPECIFIC VISCOSITY AT —° C (—° F) FOR — CUBIC CENTIMETERS} = \frac{\text{SECONDS FOR PASSAGE OF GIVEN VOLUME AT —° C (—° F)}}{\text{SECONDS FOR PASSAGE OF SAME VOLUME OF WATER AT 25° C (77° F)}}.$$

For very thin fluid bituminous materials the specific viscosity is usually determined at 25° C (77° F) with 100 cu cm. The more viscous fluid products are usually run at 40° or 50° C (104° or 122° F) with 50 cu cm and very viscous products at 100° C (212° F) or over with 50 cu cm.

Value of Viscosity Determination. Unfortunately the Engler viscosimeter is not well adapted for determining the specific viscosity of many bituminous materials at 25° C (77° F). As, for the different types of materials, viscosity at a higher temperature is no definite measure of their viscosity at 25° C (77° F), it is evident that a satisfactory comparison of their specific viscosities at normal temperature cannot be obtained by this means. As a means of such comparison the use of the instrument at higher temperatures is limited to materials of the same type. The interpretation of the test except with reference to identification and control of a given type and grade of material is therefore somewhat complicated. If, however, it is desired to apply a bituminous material at a given temperature, as for instance when it is to be heated in a tank car by means of steam, a determination of its viscosity at that temperature is often of value. It is impossible to state in a general way just what the viscosity of a material for surface application should be during application, as this is largely dependent upon the

type of distributor, its spraying nozzles and its speed control. It is a fact, however, that many materials sold for cold surface application are entirely too viscous at normal temperature for uniform distribution at the proper rate of distribution, but what may be a too high viscosity for one type of material may not be too high for another type. As a measure of consistency at normal temperature, it would appear advisable to limit the use of the Engler viscosimeter to those materials intended for cold application and when possible to utilize some other consistency test for indicating the consistency at normal temperature of those materials which have to be heated before application. In general, at normal temperature fluid distillates show a much lower specific viscosity than do fluid petroleums or tar residuums. Crude and dehydrated petroleums and tars vary greatly in viscosity. Among the petroleums, however, those of the asphaltic type are usually much more viscous than the paraffin or semiasphaltic type. Among the tars the viscosity of crude water-gas tar is lowest and gas-house coal tars from horizontal retorts the highest. Vertical and inclined retort tars usually hold an intermediate position in this respect together with coke-oven tars. For a given type of fluid residual petroleum or tar produced by fractional distillation, the specific viscosity increases with the specific gravity and decreases with the coefficient of expansion. As regards fluid residuums which are subjected to the blowing process, however, the viscosity may be greatly increased without markedly increasing the specific gravity of the residuum. The viscosity of all bituminous materials decreases as their temperature increases. In any bituminous material the presence of finely divided non-bituminous impurities held in suspension will often greatly increase the viscosity of the material, altho the actual viscosity of its pure bitumen may be low.

37. Float Test

The New York Testing Laboratory Float Test is used as a consistency test for very viscous fluid and soft semisolid bituminous materials. The float test is recommended for use by the Spec. Com. Mat. Road Cons., Am. Soc. C. E. (13). As shown in Fig. 29, the apparatus consists of two parts, an aluminum float or saucer *a* and a conical brass collar *b*. The two parts are made separately, so that one float may be used with a number of brass collars. In making the test the brass collars should be placed with the small end down upon a brass plate which has been previously amalgamated with mercury by rubbing it first with a dilute solution of mercuric chloride or nitrate and then with mercury. A small quantity of the material to be tested is heated in a metal spoon until quite fluid, care being taken that it suffers no appreciable loss by volatilization and that it is kept free from air bubbles. It is then poured into the collar in a thin stream until slightly more than level with the top. The surplus may be removed, after the material has cooled to room temperature, by means of a spatula blade which has been slightly heated. The collar and plate are then placed in ice water maintained at 5° C (41° F), and left in this bath for at least 15 min. Meanwhile a cup or pan of sufficient depth is filled about three-fourths full of water and placed on a tripod, and the water is heated to any desired temperature at which the test is to be made. This temperature should be accurately maintained and should at no time during the entire test be allowed to vary more than 0.5° C (0.9° F) from the temperature selected. After the material to be

tested has been kept in the ice water for at least 15 min, the collar and contents are removed from the plate and screwed into the aluminum float, which is then immediately floated in the warmed bath. As the plug of bituminous material becomes warm and fluid, it is gradually forced upward and out of the collar until water gains entrance to the saucer and causes it to sink. The time in seconds between placing the apparatus on the water and when the water breaks thru the bituminous material is determined by means of a stop-watch and is taken as a measure of the consistency of the material under examination. The test is preferably made at 50° C (122° F). Very soft products which show a test at this temperature of only a few seconds, however, may be advantageously tested at a lower temperature, such as 32° C (90° F). If the test at 50° C (122° F) requires over 4 or 5 min, it is sometimes made at 65° C (149° F), and, if the melting point of the material is high, the test is run at 100° C (212° F). In any case it is evident that the test temperature must be higher than the melting point of the material tested.

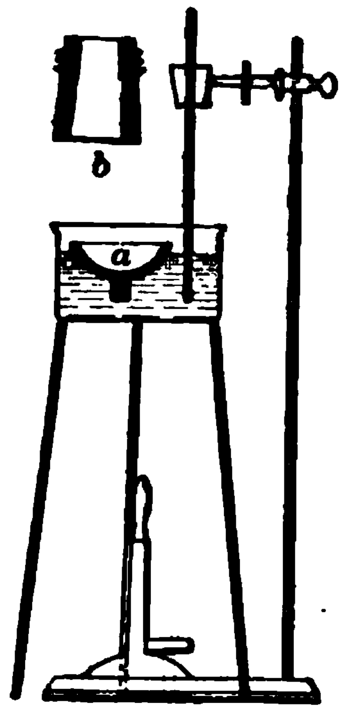


Fig. 29. N. Y. Testing Laboratory Float Apparatus

Value of the Float Test. The float test has sometimes been called a viscosity test. In some respects it is a measure of the resistance to flow possessed by the material, but it differs from the average viscosity test mainly in the fact that the temperature of the material itself is constantly changing during the test. It cannot be used with very fluid materials, but for the very viscous fluids which become almost semisolid at the temperature of ice water and for many normally semisolid products it serves as a satisfactory measure of consistency at normal temperature, altho the test itself is conducted at a higher temperature. Providing the temperature of the test is the same, it serves reasonably well as a basis of comparing the consistency at normal temperature of both straight residual and fluxed products of the same type. It has the distinct advantage over the viscosity test of being less susceptible to the influence of inert, finely divided suspended material which may be present, because of the comparatively large orifice of the collar. For this reason it more nearly represents the consistency of the actual bitumen, and is particularly well adapted for determining the consistency of tars irrespective of their free carbon content. In this connection it is used to a considerable extent as a control test in the manufacture of heavy residual tars. It is not so well adapted for testing the semisolid blown oil products which conduct heat so slowly that only the surface in contact with the collar becomes fluid before the entire plug of semisolid material is forced out. For a given type of residual material the float test at a given temperature decreases with the specific gravity. For any material it naturally decreases as the temperature of the test is increased. For fluid products which harden rapidly upon exposure, such as cut-backs, the float test is useful as a means of determining the consistency of the residue from the volatilization test (see Art. 42), especially the soft residues which cannot well be subjected to the penetration test. Most residual tars suitable for use as carpeting mediums show a float test at 50° C (122° F) of between 40 and 120 sec, while the more solid tar residues used as bituminous cements for

construction work show a float test at this temperature of from 120 to 200 sec.

38. The Penetration Test

Penetration Machines. The penetration test is one of the oldest and most widely used tests for determining the consistency of semisolid and solid petroleum and asphalt products. There are a number of penetration machines in common use which employ the same standards of test and therefore give practically equivalent results. Among them may be mentioned the Dow, the New York Testing Laboratory, and the Humboldt penetrometers. The Dow machine, shown in Fig. 30, is probably used more than any other. This apparatus consists of a standard needle *a* inserted in a short brass rod, which is held in an aluminum rod *b* by a binding screw. The aluminum rod is secured in a framework so weighted and balanced that, when it is supported on the point of the needle, the framework and rod will stand in an upright position, allowing the needle to penetrate perpendicularly without the aid of a support. The frame, aluminum rod and needle weigh 100 g with the weight *c* on the bottom of the frame, while without the weight they weigh 50 g. Fig. 30 shows the needle and weighted frame, together with side and front views of the entire apparatus, put together and ready for making a penetration. The shelf for the sample is marked *d*; *e* is the clamp to hold the aluminum rod until it is desired to make a test; and *f* is a button which, when pressed, opens the clamp. By turning this button while the clamp is being held open it will lock and keep the clamp from closing until unlocked. The device for measuring the distance penetrated by the needle consists of a rack with a foot *g*. The movement of this rack turns a pinion, to which is attached the hand which indicates on the dial *h* the vertical distance covered by the rack. One division of the dial corresponds to a movement of 0.1 mm by the rack. The rack may be raised or lowered by moving the counterweight *i* up or down. The tin box containing the sample to be tested is marked *k*; this is submerged in water contained in the glass cup in order to maintain a constant temperature. The penetration test is made as follows: A sample of the material to be tested is first warmed sufficiently to flow, and poured into the tin box. The box and contents, after cooling for 1 hr at room temperature, are immersed in water maintained at the temperature at which the test is to be made, and allowed to remain immersed for at least 1 hr. The sample in the tin box should then be placed in the glass cup and removed in it, covered with as much water as convenient without spilling, to the shelf *d*. The brass rod with the needle is inserted into *b* and secured by tightening the binding screw. The rod is lowered until the

Fig. 30. Dow Penetration Machine

point of the needle almost touches the surface of the sample; then, by grasping the frame with both hands, it is cautiously pulled down until the needle just comes in contact with the surface of the sample. This can be seen best by having a light so situated that, upon looking thru the sides of the glass cup, the needle will be reflected from the surface of the sample. After thus setting the needle, the counterweight is slowly raised until the foot of the rack rests on the head of the rod and a reading of the dial taken. The clamp is then opened wide by pressing the button and held in this position for exactly 5 sec, as determined by a pendulum or chronometer. The rack is then lowered until it rests on the rod, and the difference between the first and second readings of the dial in millimeters is taken as the distance penetrated by the needle. Owing to the susceptibility of certain bituminous materials to slight changes in temperature, the water bath should be accurately maintained at the desired temperature, both before and during the test, and, when the room temperature differs greatly from that of the bath, the water in the glass cup should be renewed after each test. An average of from three to five tests, which should not usually differ more than three units between maximum and minimum, is taken as the penetration of the sample. The needle should be removed and thoroly cleaned by wiping with a dry cloth, after which it is ready for another test. The point of the needle should be examined from time to time with a magnifying glass to see that it is not injured in any way. If it is found defective, it may be removed by heating the brass rod and withdrawing with pliers. A new needle may then be inserted in the heated brass rod, and held firmly in place by a drop of soft solder.

Am. Soc. Test. Mat. Method. In 1916, the Am. Soc. Test. Mat. adopted the following test for penetration of bituminous materials as standard:

"Definition of penetration. The consistency of a bituminous material, expressed as the distance that a standard needle vertically penetrates a sample of the material under known conditions of loading, time and temperature. Where the conditions of test are not specifically mentioned, the load, time and temperature are understood to be 100 g, 5 sec, 25° C (77° F) and the units of penetration to indicate hundredths of centimeters.

"Apparatus. The container for holding the material to be tested shall be a flat-bottomed, cylindrical dish, 55 mm (2 3/16 in) in diameter and 35 mm (1 3/8 in) deep.*

"The needle (35) for this test shall be a cylindrical steel rod 50.8 mm (2 in) long and having a diameter of 1.016 mm (0.04 in) and turned on one end to a sharp point having a 6.35-mm (1/4-in) taper. The water bath shall be maintained at a temperature not varying more than 0.1° C (0.18° F) from 25° C (77° F). The volume of water shall be not less than 10 liters and the sample shall be immersed to a depth of not less than 10 cm (4 in) and shall be supported on a perforated shelf not less than 5 cm (2 in) from the bottom of the bath. Any apparatus which will allow the needle to penetrate without appreciable friction, and which is accurately calibrated to yield results in accordance with the definition of penetration, will be acceptable. The transfer dish for container shall be a small dish or tray of such capacity as will insure complete immersion of the container during the test. It shall be provided with some means which will insure a firm bearing and prevent rocking of the container.

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*This specification is fulfilled by the American Can Company's Gill style ointment box, deep pattern, 3-oz capacity.

"PREPARATION OF SAMPLE. The sample shall be completely melted at the lowest possible temperature and stirred thoroly until it is homogeneous and free from air bubbles. It shall then be poured into the sample container to a depth of not less than 15 mm (5/8 in). The sample shall be protected from dust and allowed to cool in an atmosphere not lower than 18° C (65° F) for 1 hr. It shall then be placed in the water bath along with the transfer dish and allowed to remain 1 hr.

"TESTING. In making the test the sample shall be placed in the transfer dish filled with water from the water bath of sufficient depth to completely cover the container. The transfer dish containing the sample shall then be placed upon the stand of the penetration machine. The needle, loaded with specified weight, shall be adjusted to make contact with the surface of the sample. This may be accomplished by making contact of the actual needle point with its image reflected by the surface of the sample from a properly placed source of light. Either the reading of the dial shall then be noted or the needle brought to zero. The needle is then released for the specified period of time, after which the penetration machine is adjusted to measure the distance penetrated. At least three tests shall be made at points on the surface of the sample not less than 1 cm (3/8 in) from the side of the container and not less than 1 cm (3/8 in) apart. After each test the sample and transfer dish shall be returned to the water bath and the needle shall be carefully wiped toward its point with a clean, dry cloth to remove all adhering bitumen. The reported penetration shall be the average of at least three tests whose values shall not differ more than four points between maximum and minimum. When desirable to vary the temperature, time and weight, and, in order to provide for a uniform method of reporting results when variations are made, the samples shall be melted and cooled in air as above directed. They shall then be immersed in water or brine, as the case may require, for 1 hr at the temperature desired. The following combinations are suggested: At 0° C (32° F) 200 g weight, 60 sec; at 46.1° C (115° F) 50 g weight, 5 sec."

Method Recommended to the Am. Soc. C. E. In 1918 the Spec. Com. Mat. Road Cons. (13) recommended the adoption of the 1916 Am. Soc. Test. Mat. standard method, except that the lowest temperature at which the penetration of the asphalt cement is taken should be 4° C (39° F) instead of 0° C (32° F).

Conditions Affecting the Penetration Test. From the above descriptions it is evident that many conditions affect the results of the penetration test. For those materials which show a high penetration the diameter of the container often exerts a marked influence upon the results obtained under a given set of conditions. As a result of experiments it has been determined that for such materials the diameter of the container should not be less than 1.25 in. It is most important that thruout the test the sample be maintained at exactly the given temperature as slight differences in temperature may markedly affect the results of test. Most materials appear to continue to harden somewhat upon standing after they have been cooled to normal temperature. Thus a sample prepared and tested within a period of 2 or 3 hr will often show, under the same conditions of test, a lower penetration the following day if it is not again melted and allowed to cool just prior to making the test.

Value of the Penetration Test. The penetration test is most commonly used in connection with asphalts and asphalt cements, altho it is sometimes used in testing the harder tar residuums. For the manufacture of the

former type of materials it serves as a control test. These materials are commonly graded by their penetration at 25° C (77° F), and in all cases where the term penetration is used without other qualification it is understood that the temperature of 25° C (77° F) is implied and that the test is made with a standard needle under a load of 100 g applied for 5 sec. The test is not so useful as a means of control or in grading the tar residuums used in highway engineering for the reason that most of these residuums are quite soft, and as their surface tension is very high they press out or deform under the loaded needle much more than do the asphalt cements commonly used. The true penetration is not therefore so accurately recorded, the result obtained representing to a very considerable extent the measure of surface deformation rather than actual penetration. In general, the more susceptible the bituminous material is to temperature changes, the greater its surface deformation under the loaded needle. Susceptibility to temperature changes may be determined by means of the penetration test made at the temperatures of 0° or 4°, 25°, and 46° C (32° or 39°, 77°, and 115° F), which serve as approximate minimum, average, and maximum temperatures of the pavement proper in which the material may be incorporated.

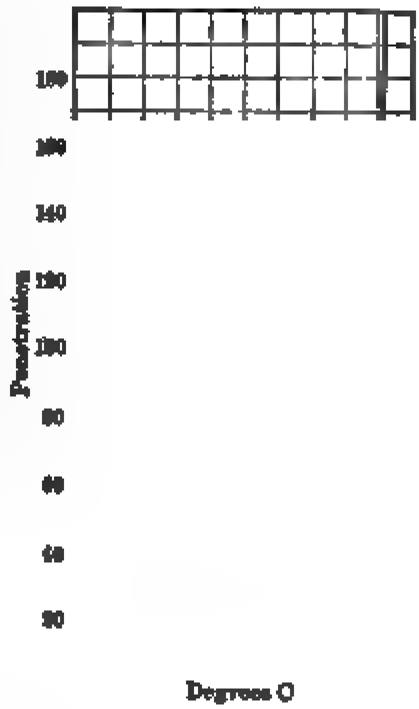

Fig. 31. Penetration of Straight Distilled and Blown Petroleums

Results of tests at 4° C (39° F) are more easily obtained than results at 0° C (32° F). Asphalt cements produced by the straight distillation of petroleums and those produced by fluxing the native asphalts with straight distilled residual fluxes are more susceptible to temperature changes than are those produced by the blowing process. This is illustrated by Fig. 31, which shows the penetration at the three temperatures of a straight distilled and a blown petroleum residuum or asphalt cement. It will be noted that while both materials show the same penetration at 25° C (77° F), the straight distilled product shows a lower penetration at 4° C (39° F) and a higher penetration at 46° C (115° F) than does the blown product. In this diagram the penetrations at 4° C (39° F) are made under a load of 200 g applied for 1 min and at 46° C (115° F) under a load of 50 g applied for 5 sec. The penetration of a given type of asphalt cement usually decreases as its specific gravity increases. In other words, it becomes harder. This relation, however, does not necessarily hold true in comparing different types. Thus an asphalt cement of given penetration produced by straight distillation of a California petroleum will usually show a much lower specific gravity than will one of the same penetration produced by the same method from a Mexican petroleum or by fluxing a native asphalt. Highly blown asphalt cements may usually be identified by a very low specific gravity as compared with residual and fluxed native asphalts of the same penetration. Thus, the penetration test, while practically valueless alone as a means of identification, owing to the fact that almost any type of material can be manufactured at any desired penetration, may be a valuable aid to

identification when considered in connection with the specific gravity of the material. No very definite general limits can be set for the proper penetration of asphalt cements for a given type of construction, as the limits vary not only with the type of material but also with the conditions which it will have to meet in service. In general, however, the penetration of asphalt cements used in the construction of sheet-asphalt or bituminous concrete pavements lies between the limits of 40 and 90, while those of higher penetration are generally used in bituminous macadam construction. Besides being applied to the original material, the penetration test is ordinarily made upon the residue obtained from the volatilization test of asphalt cements (see Art. 42) in order to determine the amount of hardening that has been produced. The penetration test is one of great importance in the plant inspection of asphalt cements prepared at the paving plant by fluxing refined asphalts. Especially where large quantities of asphalt cement are maintained for a long time at elevated temperatures, constant inspection is required, so that, as the product hardens, more flux may be added as required. In this connection a fluxing table or fluxing curve may be experimentally secured for a given refined asphalt and flux. A typical curve, showing the penetration at 25° C (77° F) of asphalt cements, produced by varying proportions of a refined asphalt and flux, is shown in Fig. 32. By means of such a curve it is a comparatively simple matter to determine at once how much flux to add to a known batch of material so as to raise the penetration from any given point to any higher point on the curve.

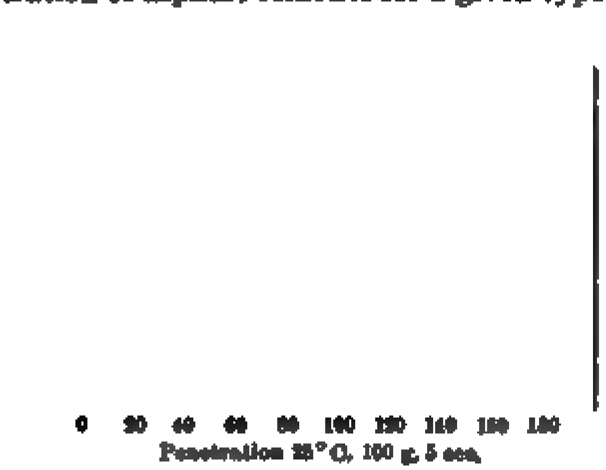

Fig. 32. Effect of Flux on Penetration of Asphalt

39. The Ductility Test

Ductility Machines of various design but operating on the same general principle have been used to a considerable extent in the testing of asphalt cements. The test was originated by Dow, whose machine is perhaps the best known. Other types in common use are the Kirschbraun machine and the Chew machine, which latter is shown in Fig. 33. In all of these machines a test specimen of the same standard size and shape is tested by pulling it apart at a given rate and noting the distance that it stretches before breaking. In some cases the pulling is accomplished by means of a gear operated by a hand wheel, but a motor drive, such as shown in the cut, is to be preferred, as it insures greater uniformity in the rate of pull. The Chew machine also has an automatic device for recording the rate of pull. The Spec. Com. Mat. Road Cons., Am. Soc. C. E. (13) recommended that the ductility test be conducted on bituminous materials as follows: "A briquet of the material to be tested shall be formed by pouring the molten material into a briquet mold. The dimension of the briquet shall be: 1 cm in thickness thruout its entire length; distance between the clips or end pieces, 3 cm; width of asphalt cement section at mouth of clips,

2 cm; width at maximum cross-section, half way between clips, 1 cm. The center pieces are removable, the briquet mold being held together during molding with a clamp or wire. The molding of the briquet shall be done as follows: the two center sections shall be well amalgamated to prevent the asphalt cement from adhering to them, and the briquet mold shall then be placed on a freshly amalgamated brass plate. The asphalt cement to be tested, while in a molten state, shall be poured into the mold, a slight excess being added to allow for shrinkage on cooling. When the asphalt cement in the mold is nearly cool, the briquet shall be cut off level, with a warm knife or spatula. When it is thoroly cooled to the temperature at which it is desired to make the test, the clamp and the two side pieces are removed, leaving the briquet of asphalt cement held at each end by the ends of the mold, which now play the part of clips. The briquet shall be kept in water for 30 min at 4° C (39° F) or 25° C (77° F) before testing, dependent upon the temperature at which the ductility is desired. The briquet with the clips attached shall then be placed in a ductility test machine filled with water at one of the above temperatures to a sufficient height to cover

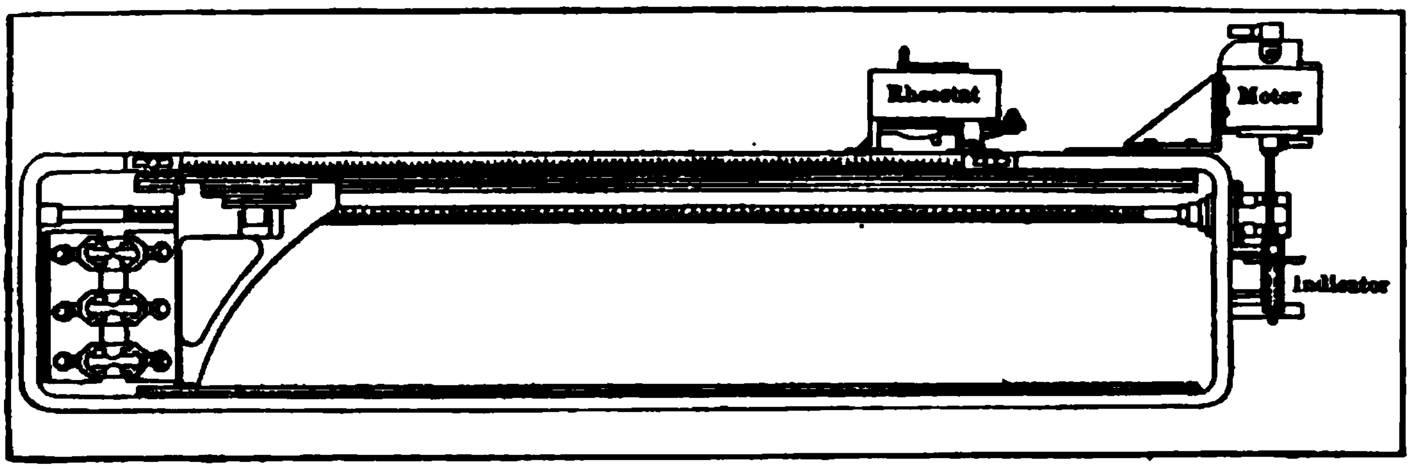

Fig. 38. Chew Ductility Machine

the briquet not less than 50 mm. This machine consists of a rectangular water-tight box, having a movable block working on a worm-gear from left to right. The left clip is held rigid by placing its ring over a short metal peg provided for this purpose; the right clip is placed over a similar rigid peg on the movable block. The movable block is provided with a pointer which moves along a centimeter scale. Before starting the test, the centimeter scale is adjusted to the pointer at zero. Power is then applied by the worm-gear pulling from left to right at the uniform rate of 5 cm per min. The distance, in centimeters, registered by the pointer on the scale at the time of rupture of the thread of asphalt cement shall be taken as the ductility of the asphalt cement."

Value of the Ductility Test. As ordinarily applied, the ductility test is of little value except as a means of identification when considered in connection with certain other tests and for control in the manufacture of certain types of bituminous materials. For a given penetration at 25° C (77° F), those materials which are most susceptible to temperature changes are the most ductile at 25° C (77° F). As for a given type of material ductility decreases with penetration, it follows that most materials with a high ductility at 25° C (77° F) show a very low ductility at 4° C (39° F). Materials which are but slightly susceptible to temperature changes, such as blown asphalts, as a rule have a low ductility at 25° C (77° F) but as their penetration at 4° C (39° F) is not so greatly changed neither is their ductility.

If the ductility test is considered as a measure of the stretch of the bituminous material when incorporated in a pavement, which stretch may be caused by contraction of the pavement, it would appear that high ductility at 25° C (77° F) should, in many cases, be undesirable because it represents low ductility at the low temperatures, which cause material contraction. As a matter of fact, it is more than doubtful if the test, as conducted, in any way represents the behavior of the comparatively thin films of material as they exist in a bituminous pavement. The theory has also been advanced that ductility is a measure of adhesiveness. Certainly those materials which appear to be most sticky at normal temperature show a high ductility at normal temperature, but if the theory holds true their adhesiveness falls off more markedly with decrease in temperature than does the initial adhesiveness of materials with a normally low ductility. Also, if this theory is unqualifiedly admitted, it would seem reasonable to conclude that the adhesiveness of an asphalt cement of, say, 60 penetration is less than that of the same type of asphalt cement of 150 penetration. The binding strength of the former is, however, known to be higher. From the above it is evident that correct interpretation of the ductility test, except as a means of identification and control, is no simple matter. In general, for a given type of bituminous material, the ductility decreases as the specific gravity increases.

40. Melting Point

Conditions Affecting the Melting Point Determination. As bituminous materials are not definite individual chemical compounds but mixtures of a great number of compounds, and as those which are ordinarily termed solids are not true solids but merely solid solutions, it follows that they can have no true melting point. In other words, pure bitumen which may be hard and brittle at normal temperature, if heated, will gradually become softer and softer until it is fluid and no critical temperature can be observed for its change from solid to liquid form. Any method of determining the melting point of bituminous materials is therefore purely arbitrary and gives purely arbitrary results. A great many methods have been devised for determining the melting point of these materials, but those perhaps most commonly used in connection with materials of interest in highway engineering are the cube method and the ring and ball method.

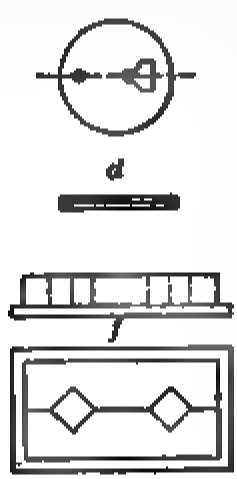

Fig. 34. Melting Point Apparatus for Cube Method

Cube Method. There are two variations to the cube method, one in which the cube of bituminous material is suspended in air and the other in which it is suspended in water. The latter is sometimes used for very soft materials which have a gravity greater than one such as the softer refined tars. Wherever possible, however, the air bath method is to be recommended This method is used by the U. S. O. P. R. and it has been recommended by the Spec. Com. Mat. Road Cons., Am. Soc. C. E. (13) for the determination of the melting point of tar products. The

melting point apparatus is shown in Fig. 34. The material to be examined is first melted in a spoon by the gentle application of heat until sufficiently fluid to pour readily. When heating, care should be taken that it suffer no appreciable loss by volatilization. It is then poured into a 0.5-in brass cubical mold *f* which has been amalgamated with mercury and which is placed on an amalgamated brass plate. The brass may be amalgamated by washing it first with a dilute solution of mercuric chloride or nitrate, after which the mercury is rubbed into the surface. By this means the bituminous material is, to a considerable extent, prevented from sticking to the sides of the mold. The hot material should slightly more than fill the mold, and, when cooled, the excess may be cut off with a hot spatula. After cooling to room temperature, the cube is removed from the mold and fastened upon the lower arm of a No. 12 wire (Brown & Sharpe gauge), *e* bent at right angles and suspended beside a thermometer in a covered Jena glass beaker, *b*, of 400 cu cm capacity, which is placed in a water bath, or, for high temperatures, a cottonseed-oil bath. The wire should be passed thru the center of two opposite faces of the cube, which is suspended with its base 1 in above the bottom of the beaker. The water or oil bath consists of an 800-cu cm low-form Jena glass beaker *a*, suitably mounted for the application of heat from below. The beaker in which the cube is suspended is of the tall-form Jena type without lip. The metal cover has two openings as shown in *d*. A cork, thru which passes the upper arm of the wire, is inserted in one hole and the thermometer in the other. The bulb of the thermometer should be just level with the cube and at an equal distance from the side of the beaker. In order that a reading of the thermometer may be made, if necessary, at the point which passes thru the cover, the hole is made triangular in shape and covered with an ordinary object glass thru which the stem of the thermometer may be seen. Readings made thru this glass should be calibrated to the angle of observation, which may be made constant by always sighting from the front edge of the opening to any given point on the stem of the thermometer below the cover. After the test specimen has been placed in the apparatus, the liquid in the outer vessel is heated in such a manner that the thermometer registers an increase of 5° C (9° F) per min. The temperature at which the bituminous material touches a piece of paper placed in the bottom of the beaker is taken as the melting point. Determinations made in the manner described should not vary more than 2° C (3.6° F) for different tests of the same material. At the beginning of this test the temperature of both bitumen and bath should be approximately 25° C (77° F).

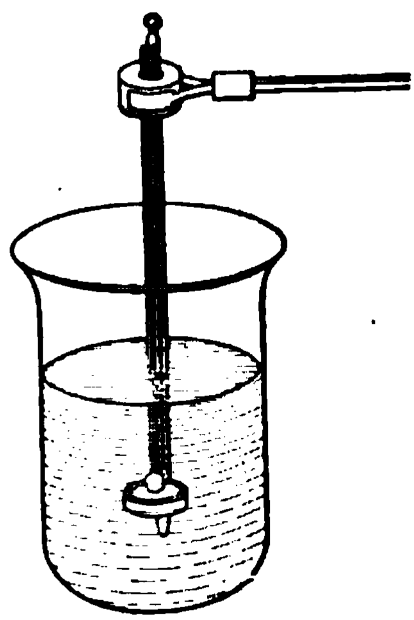

Fig. 35. Melting Point Apparatus for Ring and Ball Method

Ring and Ball Method, Am. Soc. Test. Mat. In 1916 Com. D-4 of the Am. Soc. Test. Mat. and in 1918 the Spec. Com. Mat. Road Cons., Am. Soc. C. E. (13) recommended the following method for determining the softening point of bituminous materials other than tar products, for adoption as standard:

"Definition. Ring and ball method.

"Apparatus. Brass ring 5/8 in in diameter, 1/4 in deep, 3/32 in wall, suspended 1 in above bottom of beaker. Steel ball 3/8 in in diameter, weighing between 3.45 g and 3.50 g. Standardized thermometer. Glass beaker, approximately 600 cu cm capacity. See Fig. 35.

"Operation. Carefully melt sample and fill ring with material to be tested. Remove any excess. Place ball in center of ring and suspend in beaker containing approximately 400 cu cm of water at a temperature of 5° C (41° F). Arrange thermometer bulb within ½ in of sample and at same level. Apply heat uniformly over bottom of beaker in quantity sufficient to raise temperature 5° C (9° F) per min. Record temperature at starting test and every minute thereafter until test is completed. Rate of heating is very important. Softening point is temperature at which specimen has dropped 1 in. Successive tests should average within 3° C (5.4° F). For temperatures above 95° C (203° F), glycerine should be used instead of water."

Value of the Melting Point Determination. The melting point of a bituminous material is directly related to its hardness and brittleness but the relations are not the same for all types of materials. Like most of the other physical tests it may serve as a method of control and identification. For a given type of material the melting point usually rises as the specific gravity increases and as the penetration decreases. A partly blown petroleum residuum may, however, be manipulated so as to obtain a number of combinations of penetration and melting point. Thus, if a fluid petroleum residuum is blown to a given penetration, its melting point will be much higher than tho a residuum of the same penetration had been produced by distillation alone. Intermediate melting points for that penetration may therefore be secured by varying the amount of distillation prior to or with the blowing process. High melting-point materials are as a rule less susceptible to the ordinary temperature changes than are low melting-point products. When used as a seal coat or as a filler they are therefore less likely to bleed in warm weather.

41. Flash and Burning Points

Open-Cup Method. For ordinary work the open-cup method of determining the flash and burning points of bituminous materials is sufficiently accurate. For this purpose a Cleveland or Tagliabue Oil Tester, as shown in Fig. 36, is used. Such a tester consists of a brass water or oil bath *a* resting upon a stand *b* and heated by means of a Bunsen burner. The oil to be tested is placed in the brass cup *c* and a thermometer adjusted so that its bulb is completely covered with the material. For low-flashing products the outer bath is filled with water or cottonseed oil, but for high-flashing products the space is left empty. The method of making the test is similar to that described under the closed-cup method.

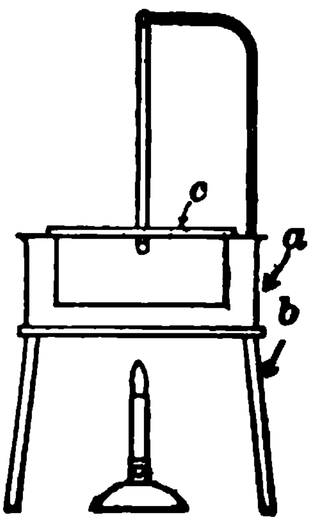

Fig. 36 Open-Cup Oil Tester

Closed-Cup Method. As determinations of flash points are subject to closer check in a closed cup than in an open cup, the closed-cup method is to be preferred for accurate work and has been recommended by the Spec. Com. Mat. Road Cons., Am. Soc. C. E. (13). For this purpose the New York State Board of Health Oil Tester, as shown in Fig. 37, is ordinarily used in the examination of bituminous materials for use in highway engineering. This instrument consists of a copper oil cup *a* of about 300 cu cm capacity, which is heated in a water or oil bath *b* by a small Bunsen flame. The cup is provided with a glass cover *c*, carrying a thermometer *d* and a hole *e* for inserting the testing flame.

The testing flame is obtained from a jet of gas passed thru a piece of glass tubing, and should be about 5 mm in length.

The FLASH TEST is made as follows: The oil-cup should first be removed and the bath filled with water or cottonseed oil. The oil may always be used and is necessary for bituminous materials flashing at a temperature of over 100° C (212° F). The oil cup should be replaced and filled with the material to be tested to within 3 mm of the flange joining the cup and the vapor chamber above. The glass cover is then placed on the oil cup and the thermometer so adjusted that its bulb is just covered by the bituminous material. The Bunsen flame should be applied in such a manner that the temperature of the material in the cup is raised at the rate of about 5° C (9° F) per min. From time to time the testing flame is inserted in the opening in the cover to about half way between the surface of the material and the cover. The appearance of a faint bluish flame over the entire surface of the bituminous material shows that the flash point has been reached and the temperature at this point is taken.

The BURNING POINT of the material may now be obtained by removing the glass cover and replacing the thermometer in a wire frame. The temperature is raised at the same rate and the material tested as before. The temperature at which the material ignites and burns is taken as the burning point. At the conclusion of this test the flame should not be blown out for danger of splashing the hot material, but a metal cover or extinguisher should be placed over the ignited material.

The Flash and Burning Point Determinations Are of Value as a quick means of differentiating heavy crude and fluid residual products. All crude fluid bituminous materials have much lower flash points than residuals, the flash points of which increase as the temperature of distillation at which they are produced increases. In general, for a given type of material, the lower its specific gravity the lower its flash point. Cut-back products produced with a light volatile flux necessarily show a lower flash point than do straight residuals of the same viscosity, float test, or penetration, and are thus quickly indicated. The flash point of asphalt cements which are not cut-back products almost invariably exceeds 163° C (325° F) and is usually higher than 200° C (392° F). Under certain working conditions the temperature at which a material flashes may be considered as a danger point and in specifications the flash point limit is often placed at a higher temperature than that to which it will be necessary to heat the material while being used. Sometimes the flash and burning points of a material are quite close together, and in other cases they are quite far apart. The relation of flash to burning point is largely dependent upon the amount present in the material of that volatile constituent which first flashes. The flash and burning points of a mixture of hydrocarbons are seldom those of the most volatile constituents as the presence of the heavier bodies tends to retard volatilization of the lighter. The flash and burning points of two or more constituents of a mixture are not additive so that those of the mixture can-

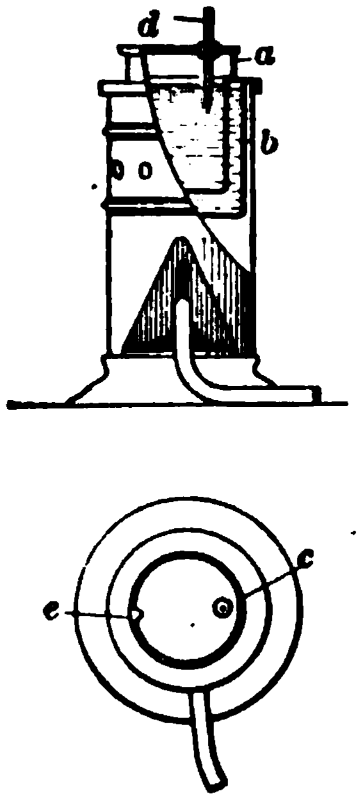

Fig. 87. N. Y. State Board of Health Oil Tester

not be predetermined. The mixture should, however, show flash and burning points lying between those of the constituents. In reports of results and in specifications, the type of cup should be indicated, as the open cup usually gives considerably higher results than the closed cup in which the evolved vapors are more or less confined.

42. Volatilization Tests

The New York Testing Laboratory Oven is most commonly used in making volatilization or evaporation tests on bituminous materials. The size and shape of oven, its method of heating, and ventilation are important factors in connection with the volatilization test, and no entirely satisfactory type has as yet been designed. Uniform temperature is also extremely important and some type of thermo-regulator is required to control the temperature. The New York Testing Laboratory Oven equipped with thermo-regulator is shown in Fig. 38. This oven is cylindrical in shape and consists of an inner compartment fitted with a circular perforated metal shelf for holding the samples under test. This shelf should be covered with a heavy perforated sheet of asbestos to minimize the direct conduction of heat from the metal to the sample holders. A cylindrical outer compartment equipped with a hinged cover at the top is fitted over the inner compartment leaving an air space between the two. The oven is heated from below by means of a ring burner with perforations systematically placed so as to equalize the flames as nearly as possible. The top or cover of the oven contains a number of openings to allow of air circulation and the insertion of thermometers and gas regulator. The oven is usually equipped with a fan or air stirrer below the shelf which may be operated from a pulley connected to a shaft which extends upward thru the center opening in the top. Use of the fan during the test, however, has been generally discontinued. A gas regulator is inserted thru one of the openings in the top of the oven, and two thermometers are inserted thru others so that their bulbs are at the same level as the samples under test. The bulb of one of these thermometers is in the air and that of the other is placed in a bath of heavy non-volatile oil. The latter serves to show the temperature of the samples during test while the former gives prompt warning of any sudden changes in temperature due to draught, irregularities in gas pressure, etc. The gas regulator should be adjusted so that the thermometer in the oil is maintained at the correct temperature of the test.

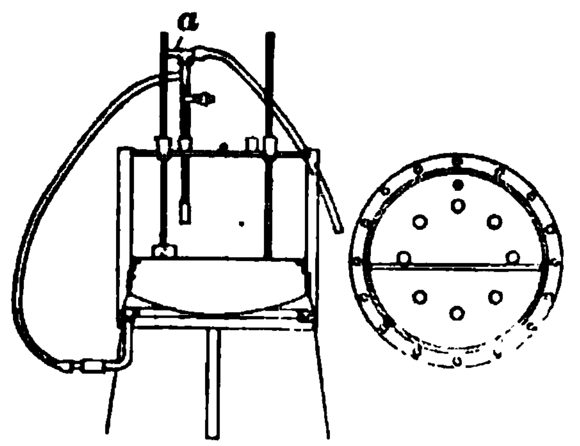

Fig. 38. N. Y. Testing Laboratory Oven

Am. Soc. Test. Mat. Method. In 1916 the Am. Soc. Test. Mat. adopted, and in 1918 the Spec. Com. Mat. Road Cons. Am. Soc. C. E. (13) recommended the following test for loss on heating of oils and asphaltic compounds for adoption as standard: "The amount lost by oils and asphaltic compounds when they are heated in an oven at a temperature of 163° C (325°F) plus or minus 1° C (2° F) shall be determined by heating 50 g of the water-free substance contained in a flat-bottomed dish, the inside dimensions of which are approximately 55 mm (2 3/16 in) in diameter by 35 mm (1 3/8 in)

deep (3-oz Gill style ointment box, deep style) for 5 hr. The oven in which the substance is heated shall be brought to the prescribed temperature before the sample is introduced, and the temperature of the sample under test shall be regarded as that of a similar quantity of the same material immediately adjoining it in the oven, in which the bulb of a standardized thermometer is immersed. The oven may be either of circular or rectangular

Fig. 39. Revolving Shelf for Volatilization Test

form and the source of heat either gas or electricity. The samples under test shall rest in the same relative position in a single row upon a perforated circular shelf 248 mm (9¾ in) in diameter, Fig. 39, suspended by a vertical shaft midway in the oven which is revolved by mechanical means at the rate of from 5 to 6 rev per min. Notes: If additional periods of heating are desired, it is recommended that they be made in successive increments of 5 hr each. If the residue after heating is to be tested for penetration, the sample should be thoroly mixed by stirring until it is cool, and thereafter manipulated in accordance with the directions of the standard test for penetration of bituminous materials."

Conditions Affecting the Volatilization Test. Besides the oven itself and the temperature employed, there are a number of other conditions that affect the volatilization test. The most important of these is the relation of exposed surface area to the volume of sample tested. This means that for a given diameter of container variable percentages of loss, by volatilization will occur for different volumes or weights of a given sample which is tested. This particularly true for materials that show a high loss under the test, and as the consistency of the residue is largely dependent upon the percentage of loss by volatilization, it follows that for a given temperature and time of test the penetration of the residue will vary with the relation of the diameter of the container and the weight of sample tested. It will be noted that in the two methods above described the diameter specified for the container is approximately the same, but that one method

specifies a 20 g sample while the other specifies a 50 g sample. In reporting results, therefore, it is customary to indicate the weight of sample tested as well as the temperature and time of test. The 20 g sample has been most commonly used for the harder grades of asphalt cements, but as this amount does not afford sufficient depth for a determination of the penetration of the residue obtained from the softer asphalt cements, a strong preference is being shown for the 50 g sample. Stirring the sample after the 3 and 4 hr period, as described in the preceding paragraph, is not common practice. It involves the weighing of a stirring rod for each sample. The ordinary procedure is to allow the test to run for five continuous hours.

Value of the Volatilization Test. The volatilization test at 163° C (325° F) is commonly made upon petroleum and asphalt products but seldom upon tar products. The temperature was originally selected as being that at which a refined asphalt is usually fluxed to produce an asphalt cement. With few exceptions, it may also be considered as the maximum allowable temperature to heat bituminous materials for direct use. Materials which are likely to be heated to this temperature should preferably show an open flash test which is higher. Asphalt cements of the consistency which is desired to be maintained after use should show a low loss under the volatilization test and the residue should not show an undue decrease in penetration or hardening as compared with the original sample. Carefully prepared asphalt cements of less than 100 penetration at 25° C (77° F) do not as a rule show a loss of over 1 or 2%, and the same is true of most fluxed native asphalts, altho those produced from Bermudez asphalt may run slightly higher. For such products it is customary to specify that the penetration of the residue at 25° C (77° F) shall be not less than 50% of that of the original material at 25° C (77° F). Heavy residual fluxes as a rule show a loss of less than 5% under this test. On the other hand, cut-back asphalts are supposed to show a relatively high loss and to harden materially when subjected to the volatilization test. Irrespective of the consistency of the original material, the residues from cut-back asphalts should show a penetration which is not materially higher than that which it is desired to maintain under service conditions. When testing fluxed products such as carpeting mediums the residue from the volatilization test may be subjected to the float test if too soft for its penetration to be determined. This is particularly valuable where the float test can be made upon both the original material and its residue. In some cases the volatilization test is made at other temperatures than 163° C (325° F). Thus the tendency of a material to harden very rapidly after use is shown by a test at 100°, 105° or 110° C (212°, 221° or 230° F). If the test is to be made upon a tar product a relatively low temperature should be used, as 163° C (325° F) is unnecessarily severe for tars, owing to the fact that it is never necessary to heat them to this temperature during use and if they are so heated they are apt to be seriously injured. In general, for a given type of residual product, the loss by volatilization decreases with increase in specific gravity, flash point, and specific viscosity or float test, and decreases in penetration if it is a semisolid or solid.

Evaporation Test for Determining Percent of Asphalt. An evaporation or volatilization test has been used to some extent in determining the so-called asphalt content of fluid petroleum products. In such a test a weighed quantity of the material is heated in an open dish. At intervals the sample is allowed to cool and its penetration taken at 25° C (77° F). When the residue shows a penetration of approximately 100 it is weighed. The weight

percentage of such residue is then reported as the asphalt content of the material. In some cases a maximum temperature of 260° C (500° F) is specified. At considerably lower temperatures, however, chemical changes are often produced in the material tested and the residue does not then represent asphalt which was present in the original material but asphalt which is actually manufactured by the test itself. Such asphalt would in most cases never be developed under ordinary conditions of use and the term asphalt content as applied to the results of this test is therefore misleading. In 1914 the Committee on "Standard Tests for Road Materials" of the Am. Soc. Test. Mat. recommended that the use of the term asphalt content be discontinued. The test itself is inaccurate and greatly affected by conditions which are seldom taken into account. Thus the percentage of residue will vary with the temperature employed, and the frequency of stirring the heated sample if it is stirred, as oxidation is largely responsible for the hardening. A higher percentage of residue of a given penetration may usually be obtained by frequent stirring than by undisturbed volatilization, owing to more intimate contact of the oxygen of the air with the mass of material.

43. Distillation Tests

Am. Soc. Test. Mat. Method. In 1916 the following method for the distillation of bituminous materials suitable for road treatment was adopted as standard by the Am. Soc. Test. Mat., and in 1918 the Spec. Com Mat. Road. Cons., Am. Soc. C. E. (13) recommended
llation tests of complicated hydro-
carefully standardized in all details
btained by different operators. The
selected after an exhaustive investi-
thods which were in common use.
le as received shall be thoroly stirred
necessary, to insure a complete mix-
r analysis is removed.
ie presence of water is suspected or
l be dehydrated before distillation.
material is placed in an 800 cu cm
a distilling head connected with a
A ring burner is used, starting
at the top of the still, and grad-
f necessary, until all the water has
The distillate is collected in a 200 cu cm separatory funnel with the tube cut off close to the stopcock. When all the water has been driven over and the distillate has settled out, the water is drawn off and the oils returned to the residue in the still. The contents of the still shall have cooled to below 100° C (212° F) before the oils are returned, and they shall be well stirred and mixed with the residue.

"Apparatus. The apparatus shall consist of the following standard parts:

Fig. 40. Distillation Apparatus

"Flask. The distillation flask shall be a 250 cu cm Engler distilling flask, having the following dimensions:

Diameter of bulb	8.0 cm
Length of neck	15.0 cm
Diameter of neck	1.7 cm
Surface of material to lower side of tubulature	11.0 cm
Length of tubulature	15.0 cm
Diameter of tubulature	0.9 cm
Angle of tubulature	75°

A variation of 3% from the above measurements will be allowed.

"Thermometer. The thermometer shall conform to the following requirements:

"It shall be made of thermometric glass of a quality equivalent to suitable grades of Jena or Corning make. It shall be thoroly annealed. It shall be filled above the mercury with inert gas which will not act chemically on or contaminate the mercury. The pressure of the gas shall be sufficient to prevent separation of the mercury column at all temperatures of the scale. There shall be a reservoir above the final graduation large enough so that the pressure will not become excessive at the highest temperature. The thermometer shall be finished at the top with a small glass ring or button suitable for attaching a tag. Each thermometer shall have for identification the maker's name, a serial number, and the letters 'A. S. T. M. Distillation.'

"The thermometer shall be graduated from 0° to 400° C at intervals of 1° C. Every fifth graduation shall be longer than the intermediate ones, and every tenth graduation beginning at zero shall be numbered. The graduation marks and numbers shall be clear-cut and distinct.

"The thermometer shall conform to the following dimensions:

Total length, maximum	385 mm;	
Diameter of stem	7 mm;	permissible variation, 0.5 mm;
Diameter of bulb, minimum	5 mm;	and shall not exceed diameter of stem;
Length of bulb	12.5 mm;	permissible variation, 2.5 mm;
Distance of 0° to bottom of bulb	30 mm;	permissible variation, 5 mm;
Distance from 0° to 400°	295 mm;	permissible variation, 10 mm.

"The accuracy of the thermometer when delivered to the purchaser shall be such that when tested at full immersion the maximum error from 0° to 200° C shall not exceed the following:

From 0° to 200° C	0.5° C;
From 200° to 300° C	1.0° C;
From 300° to 375° C	1.5° C.

"The sensitiveness of the thermometer shall be such that when cooled to a temperature of 74° C below the boiling point of water at the barometric pressure, at the time of test, and plunged into free flow of steam, the meniscus shall pass the point 10° C below the boiling point of water in not more than 6 sec.

"The thermometer shall be set up as for the distillation test, using water, naphthalene, and benzophenone as distilling liquids. The correctness of the thermometer shall be checked at 0° and 100° C after each third distillation until seasoned."

"Condenser. The condenser tube shall have the following dimensions:

Adaptor	70 mm
Length of straight tube	185 mm
Width of tube	12 to 15 mm
Width of adaptor end of tube	20 to 25 mm

"Stands. Two iron stands shall be provided, one with a universal clamp for holding the condenser, and one with a light grip arm with a cork-lined clamp for holding the flask.

"Burner and Shield. A Bunsen burner shall be provided, with a tin shield 20 cm long by 9 cm in diameter. The shield shall have a small hole for observing the flame.

"Cylinders. The cylinders used in collecting the distillate shall have a capacity of 25 cu cm and shall be graduated in tenths of a cubic centimeter.

"Setting up the Apparatus. The apparatus shall be set up as shown in Fig. 40, the thermometer being placed so that the top of the bulb is opposite the middle of the tubulature. All connections should be tight.

"Method. One hundred cubic centimeters of the dehydrated material to be tested shall be placed in a tared flask and weighed. After adjusting the thermometer, shield, condenser, etc, the distillation is commenced, the rate being so regulated that 1 cu cm passes over every minute. The receiver is changed as the mercury column just passes the fractionating point. The following fractions should be reported: Start of distillation to 110° C; 110° to 170° C; 170° to 235° C; 235° to 270° C; 270° to 300° C; residue. To determine the amount of residue, the flask is weighed again when distillation is complete. During the distillation the condenser tube shall be warmed when necessary to prevent the deposition of any sublimate. The percentages of fractions should be reported both by weight and by volume."

Standard Creosoters' Distillation Test. While the preceding method is suitable for use in connection with the distillation of all types of bituminous materials, the following method as given in Bulletin 65 of the American Railway Engineering and Maintenance of Way Association has been widely used in the examination of creosoting oils. The apparatus as shown in Fig. 41 consists of a glass-stoppered retort having a capacity of approximately 8 oz up to the bend of the neck when the bottom of the retort and the mouth of the off-take are in the same plane. A nitrogen-filled mercury thermometer graduated in full degrees Centigrade is used for recording the temperatures. The following is further specified: "The bulb of the retort and at least 2 in of the neck must be and remain covered with a shield of heavy asbestos paper, shaped as shown in diagram, during the entire process of distillation, so as to prevent heat radiation, and between the bottom of the retort and the flame of the lamp or burner two sheets of wire gauze, each 20-mesh fine and at least 6 in square, must be placed. It is also recommended that the flame be protected against air currents. An ordinary tin can, from which a portion of the bottom and all of the top have been removed, placed on a support attached to the burner, as shown in diagram, has been found to answer the purpose. Before beginning the distillation the retort should be carefully weighed and exactly 100 g of the oil placed therein, the same being weighed in the retort.

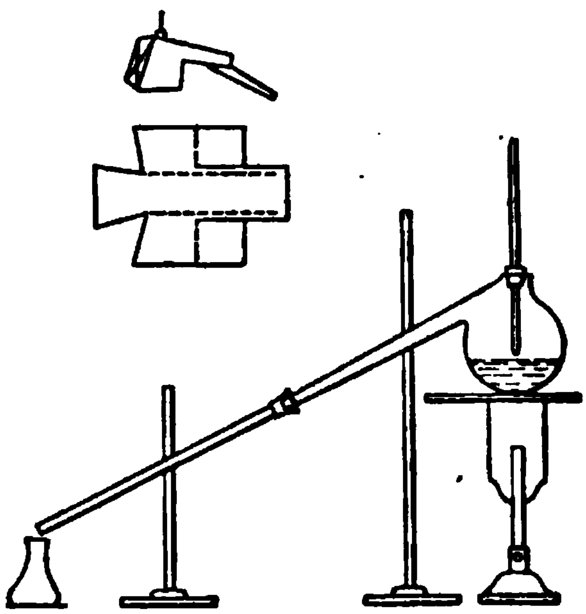

Fig. 41. Standard Creosoters' Distillation Apparatus

The thermometer should be inserted in the retort with the lower end of the bulb ½ in from the surface of the oil, and the condensing tube attached to the retort by a tight cork joint. The distance between the bulb of the thermometer and the end of the condensing tube should not be less than 20 nor more than 24 in, and during the progress of the distillation the thermometer must remain in its original position. The distillates should be collected in weighed bottles and all fractions determined by weight. Reports are to be made on the following fractions: 0° to 170° C; 170° to 200° C; 200° to 210° C; 210° to 235° C; 235° to 270° C; 270° to 315° C; 315° to 355° C. For practical purposes there will be no need of reporting on all of these fractions. It will be sufficient to report on the fractions as follows: below 200° C; 200° to 210° C; 210° to 235° C; 235° to 315° C; above 315° C. Reports are to be made on individual fractions. In making such reports, it is to be distinctly understood that those fractions do not necessarily refer to individual compounds. In other words, the fractions between 210° and 235° C will not necessarily be all naphthalene, but will probably contain a number of other compounds. The distillation should be a continuous one and should take about 45 min. When any measurable quantity of water is present in the oil, the distillation should be stopped, the oil separated from the water, and returned to the retort, when the distillation should be recommenced and the previous readings discarded."

Value of Distillation Test. The distillation test as applied to tars is valuable both as a means of ascertaining their method of preparation and suitability for a given purpose. In this connection it takes the place of the volatilization test, which is usually restricted to the examination of petroleum and asphalt products. All crude tars contain water and the appearance of water in the distillate therefore indicates a crude material, especially if accompanied by an appreciable quantity of light oil. Heavy refined tars which have become contaminated with water show a sudden rise in distillation temperature after the water has been removed. The presence of high percentages of naphthalene is indicated by the proportion of the various distillates which solidify upon cooling. In this connection it is always well to note the character of each fraction obtained. The extent of distillation in the manufacture of the original material is indicated by the temperature at which distillation commences in the test and the relative quantities of the fractions obtained. Cut-back products usually show an abnormal amount of some given fraction as compared to the amount that would be obtained from a straight distilled residue of the same consistency. After the distillation test is completed it is often of interest to determine the melting point of the pitch residue which, if obtained by distillation to 300° C, should seldom e ceed 75° C. Tar distillates are soluble in dimethyl sulphate while petroleum and asphalt distillates are not. Mixtures of tar with petroleum or asphalt products are therefore detected by the presence of an appreciable quantity of distillate, which when shaken up with an excess of dimethyl sulphate shows a separation of insoluble material. A fraction distilling above 300° C is usually selected for the dimethyl sulphate test (34a) when the presence of a petroleum or asphalt product is suspected. Different tars vary so in character that it is difficult to define the exact relation of the distillation test to other tests. In general, however, for a given type of residual tar the percentage of total distillate decreases as the specific gravity and viscosity or float test increases.

44. Total Bitumen

Carbon Disulphide. According to standard definition, all bitumen is soluble in carbon disulphide. The percent of total bitumen in a bituminous material is therefore determined by its solubility in carbon disulphide. This solvent is an etherial mobile liquid which is extremely inflammable and should be handled with great care. It is very volatile and when mixed with air its vapors spontaneously ignite at a temperature slightly higher than that of live steam. When used for testing bituminous materials extraordinary precautions should therefore be taken to prevent possible fire or explosion.

The Ordinary Filtration Method substantially as described by Hubbard and Reeve (25b) and recommended by the Spec. Com. Mat. Road Cons., Am. Soc. C. E. (13), is as follows:

This test consists in dissolving the bituminous material in carbon disulphide and recovering any insoluble matter by filtering the solution thru an asbestos felt. The form of Gooch crucible best adapted for the determination is 4.4 cm wide at the top, tapering to 3.6 cm at the bottom, and is 2.5 cm deep. For preparing the felt the necessary apparatus is arranged as shown in Fig. 42, in which *a* is the filtering flask, *b* a rubber stopper, *c* the filter tube, and *d* a section of rubber tubing which tightly clasps the Gooch crucible *e*. The asbestos is cut with scissors into pieces not exceeding 1 cm in length, after which it is shaken up with just sufficient water to pour easily. The crucible is filled with the suspended asbestos, which is allowed to settle for a few moments. A light suction is then applied to draw off all the water and leave a firm mat of asbestos in the crucible. More of the suspended material is added, and the operation is repeated until the felt is so dense that it scarcely transmits light when held so that the bottom of the crucible is between the eye and the source of light. The felt should then be washed several times with water, and drawn firmly against the bottom of the crucible by an increased suction. The crucible is removed to a drying oven for a few minutes, after which it is ignited at red heat over a Bunsen burner, cooled in a dessicator and weighed. From 2 to 3 g of bituminous material or about 10 g of an asphalt topping or rock asphalt is now placed in the Erlenmeyer flask, which has been previously weighed, and the accurate weight of the sample is obtained. One hundred cubic centimeters of c. p. carbon disulphide is poured into the flask in small portions, with continual agitation, until all lumps disappear and nothing adheres to the bottom. The flask is then corked and set aside for 15 min. After being weighed, the Gooch crucible containing the felt is set up over the dry pressure flask, as shown in Fig. 42, and the solution of bitumen in carbon disulphide is decanted thru the felt without suction by gradually tilting the flask, with care not to stir up any precipitate that may have settled out. At the first sign of any sediment coming out, the decantation is stopped and the filter allowed to drain. A small amount of carbon disulphide is then washed down the sides of the flask, after which the precipitate is brought upon the felt and the flask scrubbed, if necessary, with a feather or "policeman," to remove all adhering material. The contents of the crucible are washed with carbon disulphide until the washings run colorless. Suction is then applied until there is practically no odor of carbon disulphide in the crucible, after which

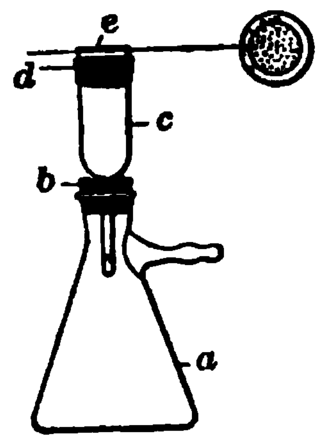

Fig. 42. Filtration Apparatus

the outside of the crucible is cleaned with a small amount of the solvent. The crucible and contents are dried in a hot-air oven at 100° C (212° F) for about 20 min, cooled in a desiccator, and weighed. If any appreciable amount of insoluble matter adheres to the flask, it should also be dried and weighed, and any increase over the original weight of the flask should be added to the weight of insoluble matter in the crucible. The total weight of insoluble material may include both organic and mineral matter. The former, if present, is burned off by ignition at a red heat until no incandescent particles remain, thus leaving the mineral matter or ash, which can be weighed on cooling. The difference between the total weight of material insoluble in carbon disulphide and the weight of substance taken equals the total bitumen, and the percentage weights are calculated and reported as total bitumen, and organic and inorganic matter insoluble, on the basis of the weight of material taken for analysis. This method is quite satisfactory for straight oil and tar products, but where native asphalts are present it will sometimes be found practically impossible to retain all of the finely divided mineral matter on an asbestos felt. It is, therefore, generally more accurate to obtain the result for total mineral matter by direct ignition of a 1 g sample in a platinum crucible or to use the result for ash obtained in the fixed carbon test. The total bitumen is then determined by deducting from 100% the sum of the percentages of total mineral matter and organic matter insoluble. If the presence of a carbonate mineral is suspected, the percentage of mineral matter may be most accurately obtained by treating the ash from the fixed carbon determination with a few drops of ammonium carbonate solution, drying at 100° C (212° F), then heating for a few minutes at a dull red heat, cooling, and weighing again. When difficulty in filtering is experienced, as when Trinidad asphalt is present in any amount, a period of longer subsidence than 15 min is necessary, and the following standard method adopted in 1911 by the Am. Soc. Test. Mat. is recommended.

Am. Soc. Test. Mat. Method. " After drying, from 2 to 15 g, as may be necessary to insure the presence of 1 to 2 g of pure bitumen, are weighed into a 150-cu cm tared Erlenmeyer flask, and treated with 100 cu cm of carbon disulphide. The flask is then loosely corked and shaken from time to time until all large particles of the material have been broken up. It is then set aside for 48 hr to settle. The solution is decanted into a similar flask that has been previously weighed. As much of the solvent is poured off as possible without disturbing the residue. The contents of the first flask are again treated with fresh carbon disulphide, shaken as before, and put away with the second flask for 48 hr to settle.

" The liquid in the second flask is then carefully decanted upon a weighed Gooch crucible, 3.2 cm in diameter at the bottom, fitted with an asbestos filter, and the contents of the first flask are similarly treated. The asbestos filter is made of ignited long-fiber amphibole, packed in the bottom of a Gooch crucible to the depth of not over ⅛ in. In filtering, no vacuum is to be used and the temperature is to be kept between 20° and 25° C. After passing the liquid contents of both flasks thru the filter, the residue on the filter is thoroly washed, and the residues remaining in them are shaken with more fresh carbon disulphide and allowed to settle for 24 hr, or until it is seen that a good subsidation has taken place. The solvent in both flasks is then again decanted thru the filter, and the residues remaining in them are washed until the washings are practically colorless. All washings are to be passed thru the Gooch crucible.

"The crucible and both flasks are then dried at 125° C and weighed. The filtrate containing the bitumen is evaporated, the bituminous residue burned, and the weight of the ash thus obtained added to that of the residue in the two flasks and the crucible. The sum of these weights deducted from the weight of substance taken gives the weight of soluble bitumen."

Centrifugal Method. A number of centrifugal methods have been devised for the extraction and determination of bitumen in bituminous aggregates. No one method is ideal for all conditions, but the following method, as described by Hubbard and Reeve (25b) is of particular interest in connection with the determination of total bitumen in coarse bituminous aggregates. It is also useful for the purpose of recovering the extracted bitumen and aggregate for subsequent examination. The apparatus used is shown in Fig. 43.

It consists of a 1/8 h.p. 1100 rev per min vertical shaft electric motor *a* with the shaft projecting into the cylindrical copper box *b*, the bottom of which is so inclined as to drain to the spout *c*. A 3/16 in circular brass plate 9½ in in diameter is shown in *d*, and upon this rests the sheet-iron bowl *e*, which is 8½ in in diameter by 2 5/16 in high, and has 2 in circular hole in the top. Fastened to the inner side of the bowl is the brass cup *f*, having a circle of 1/8 in holes for the admission of the solvent, and terminating in the hollow axle, which fits snugly thru a hole at the center of the brass plate. The bowl may be drawn firmly against a felt-paper ring *g*, ¾ in wide, by means of the 2½ in milled nut *h*, for which the hollow axle is threaded for a distance of ¾ in directly below the upper surface of the plate. The axle fits snugly over the shaft of the motor, to which it is locked by a slot and cross pin *i*. The aggregate is prepared for analysis by heating it in an enamelware pan on the hot plate until it is sufficiently soft to be thoroly disintegrated by means of a large spoon. Care must be taken, however, that the individual particles are not crushed. If a section of pavement is under examination, a piece weighing somewhat over 1 kg may be cut off with hammer and chisel. The disintegrated aggregate is then allowed to cool, after which a sufficient amount is taken to yield on extraction from 50 to 60 g of bitumen. It is placed in the iron bowl and a ring ¾ in wide, cut from the felt paper, is fitted on the rim, after which the brass plate is placed in position and drawn down tightly by means of the milled nut. If the bitumen is to be recovered and examined, the felt ring should be previously treated in the empty extractor with a couple of charges of carbon disulphide in order to remove any small amount of grease or rosin that may be present altho a proper grade of felt should be practically free from such products. The bowl is now placed on the motor shaft and the slot and pin are carefully locked. An empty bottle is placed under the spout and 150 cu cm of carbon disulphide is poured into the bowl thru the small holes. The cover is put on the copper box and, after allowing the material to digest for a few minutes, the motor is started, slowly at first in order to permit the aggregate to distribute uniformly. The speed should then be increased sufficiently by means of the regulator to cause the dissolved bitumen to flow from the spout in a thin stream. When the first charge has drained, the motor is stopped and a

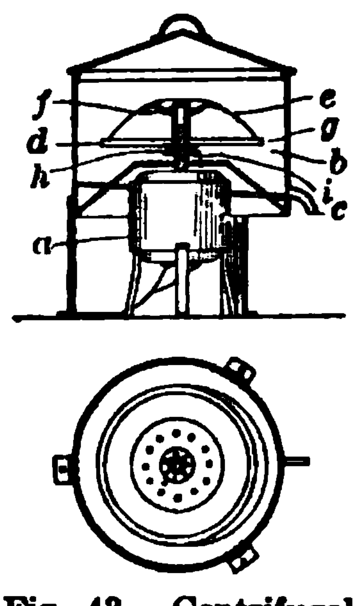

Fig. 43. Centrifugal Extractor

fresh portion of disulphide is added. This operation is repeated from four to six times with 150 cu cm of disulphide. With a little experience the operator can soon gage exactly what treatment is necessary for any given material. When the last addition of solvent has drained off, the bowl is removed and placed with the brass plate uppermost on a sheet of manila paper. The brass plate and felt ring are carefully laid aside on the paper and, when the aggregate is thoroly dry, it can be brushed on a pan of a large balance and weighed. The difference between this weight and the original weight taken shows the amount of bitumen extracted. The aggregate may then be tested as occasion requires.

Recovery of Extracted Bitumen. When it is desired to recover a sample of the extracted bitumen from a total bitumen determination, the solution of bitumen should be allowed to stand overnight in order to permit the settling of any fine mineral matter that is sometimes carried thru the felt ring in the extractor. The solution is then decanted into a flask and the solvent is driven off by means of heat from an incandescent lamp until the residue is of a thick sirupy consistency. Meanwhile the solvent is condensed and recovered in any suitable manner. The residue is poured into an 11-cm porcelain evaporating dish, and evaporated on a steam bath. The most scrupulous care must be taken at all times that no flames are in its immediate vicinity. Evaporation is carried on at a gentle heat, with continual stirring, until foaming practically ceases. It is advisable to have a large watch glass at hand to smother the flames quickly should the material ignite. As the foaming subsides, the heat of the steam bath may be gradually raised, and evaporation is continued until the bubbles beaten or stirred to the surface of the bitumen fail to give a blue flame or odor of sulphur dioxide when ignited by a small gas jet. The dish of bitumen should then be set in a hot-air oven maintained at 105° C (221° F) for about an hour after which it is allowed to cool. Its general character is noted and any tests for bitumens that are necessary are then made upon it.

Value of Total Bitumen Determination. The total bitumen determination is ordinarily made upon all types and grades of bituminous materials. There appears to be a strong tendency toward the purchase of bituminous materials upon a bitumen basis, as determined by their solubility in carbon disulphide. This is a perfectly rational practice in the case of liquid bituminous materials and bituminous cements, but not for bituminous aggregates such as asphalt block, rock asphalts, etc. All bituminous distillates produced by fractional distillation are completely soluble in carbon disulphide. Residual petroleum products should also be almost completely soluble. A small amount of still ash and extraneous organic matter is, however, usually present and an allowance of approximately 0.5% may therefore be made for total material insoluble in carbon disulphide. If the organic matter insoluble exceeds 0.5% there is strong indication that the petroleum has been cracked or locally overheated with possible resultant injury to the finished product. Native asphalts and products produced by fluxing the native asphalts ordinarily contain appreciable amounts of both mineral matter and organic matter insoluble in carbon disulphide. Gilsonite is one of the few exceptions to this rule. Where the exact percentage of total insoluble matter is known for a refined native asphalt, it is possible to compute with considerable accuracy the amount of such asphalt present in an asphalt cement produced by fluxing it. In such computation the petroleum flux is assumed to be completely soluble unless information to the contrary has been secured. Practically all of the material in tar prod-

ucts which is insoluble in carbon disulphide consists of organic matter or free carbon, and the percentage of free carbon is thus determined. Refined water-gas tars may be distinguished from refined coal tars of the same consistency by their relatively small percentage of free carbon. Gas-house coal tars, particularly those produced from horizontal retorts, may usually be distinguished from coke-oven tars and vertical retort tars by their relatively high percentage of free carbon. For refined tars of the same viscosity or float test, the specific gravity becomes higher as the solubility in carbon disulphide decreases. The same is true of asphalt cements produced from the same native asphalt if such asphalt contains insoluble material. As the solubility of a bituminous material in carbon disulphide is entirely dependent upon the non-bituminous constituents present, it is evident that no definite relations can be expressed between the physical and chemical properties of the actual bitumen present and the solubility of the material in this solvent. In other words, irrespective of specific gravity, consistency and other properties, all pure bitumen dissolves in carbon disulphide. An oily, greasy distillate is therefore just as much bitumen as a hard brittle residue. The total bitumen determination is particularly valuable as a laboratory control test in the preparation of bituminous aggregates. The serviceability of a bituminous aggregate is not only dependent upon the physical and chemical properties of the bituminous cement but also upon the percentage of such cement which is present. Too much may be almost as bad as too little, and the exact percentage should therefore be adjusted to meet the character and grading of the mineral aggregate which is used. When once the proper combination of bituminous cement and a given aggregate has been experimentally ascertained, the percent of bitumen as determined by test should, for different lots of the same bituminous aggregate, fall within comparatively narrow limits.

Rational Percent of Bitumen in Bituminous Aggregates. The determination of the percentage of bitumen in a bituminous material as ordinarily made is upon a weight basis. As a means of comparing different bituminous aggregates the weight basis is irrational unless the relations of weight to volume are the same for the mixtures compared. In any bituminous aggregate the volume of bitumen is a most important factor from the standpoint of covering capacity, thickness of film and, in some cases, the reduction of voids. In view of the rather wide variation in specific gravity of ordinary bituminous cements and mineral aggregates the volume method of comparison is the most rational. The volume or rational percent of bitumen in a bituminous aggregate may be determined by recovery of the bitumen after its extraction and determination upon a weight basis. The specific gravity of the recovered bitumen should be determined as well as that of the mineral aggregate. From this data the volume proportions of each are ascertained by dividing their weight percent by their respective specific gravity. These proportions transposed to total 100 are the rational or volume percentages of the constituents. The formula for expressing the rational percent of bitumen is as follows, where x represents the rational percent of bitumen, p the weight percent of bitumen, a the specific gravity of the bitumen, and b the specific gravity of the aggregate.

$$x = \frac{100\,p\,b}{pb + a\,(100 - p)}$$

The importance of the use of the rational percent of bitumen as a basis of comparison may be illustrated by considering two bituminous aggre-

gates which contain 6% by weight of bitumen and are practically identical in so far as the consistency of bitumen and grading of the aggregate are concerned. According to the ordinary interpretation of results of analysis, the two mixtures might be considered as equivalents. If, however, it is found that the first mix is composed of an aggregate with a specific gravity of 2.50 while the recovered bitumen shows a specific gravity of 1.17 and that the aggregate of the second mix has a specific gravity of 3.50 while the recovered bitumen shows a specific gravity of 0.960, the rational percent of bitumen would be found to differ greatly in the two mixes, as follows:

Constituents	Percent by Weight		Specific Gravity		Rational Proportion		Rational Percent
First Mix							
Aggregate	94	÷	2.50	=	37.6	=	88.0
Bitumen	6	÷	1.17	=	5.1	=	12.0
	100						100.0
Second Mix							
Aggregate	94	÷	3.50	=	26.9	=	81.0
Bitumen	6	÷	0.96	=	6.3	=	19.0
	100						100.0

From the results given in the last column it is evident that the first mix has a bitumen equivalent of about two-thirds that of the second mix, altho the percentages by weight are the same. The variation of 7% bitumen (which is the difference between the rational percentages 19 and 12) might, for a given type of aggregate, mean the difference between success and failure.

45. Naphtha Insoluble Bitumen (Asphaltenes)

Petroleum Naphthas are not definite chemical compounds, but are composed of a number of hydrocarbons which vary in character and quantity according to the petroleum from which they have been distilled. Their solvent action upon petroleum and asphalt products therefore varies greatly. Thus, naphthas produced from asphaltic petroleums, consisting mainly of naphthene and polymethylene hydrocarbons, are much more powerful solvents of the heavier asphaltic hydrocarbons than are the paraffin naphthas. Moreover, the solvent power of any given type of naphtha increases with its specific gravity. As the main object of the naphtha insoluble bitumen test is to separate the heavier hydrocarbons of an asphaltic nature from the other constituents, a light paraffin distillate is usually employed. One of 86° B gravity distilling between 40° and 65° C (104° and 149° F) has been used to a considerable extent, as has also an 88° B naphtha, the solvent power of which is approximately the same as that of the 86° B products. Heavier naphthas, such as 66° B and 72° B, are also less frequently used.

Method of Determination. The bitumen in petroleum and asphalt products which is insoluble in paraffin naphtha is known as asphaltenes. As the percentage of asphaltenes, as determined by test, is largely dependent upon the gravity and type of naphtha used as a solvent, a report of results should state the gravity of the naphtha and preferably its boiling point limits as well. The determination is not entirely satisfactory and investigations have been conducted with a view to finding some solvent of definite chemical composition which will satisfactorily replace naphtha and more nearly insure uniform results on the part of different analysts. Pentane, alcohol and ether have been suggested for this purpose but have not been generally used. The following method for determining bitumen insoluble

in paraffin naphtha is as described by Hubbard and Reeve (25b). This determination is made in the same general manner and with the same apparatus as described in the second paragraph of Art. 44 under THE ORDINARY FILTRATION METHOD for the determination of total bitumen, except that 100 cu cm of 86° B paraffin naphtha is employed as a solvent instead of carbon disulphide. Considerable difficulty is sometimes experienced in breaking up the heavy semisolid bituminous materials; the surface of the material is attacked, but it is necessary to remove some of the insoluble matter in order to expose fresh material to the action of the solvent. It is, therefore, advisable to heat the sample after it is weighed, allowing it to cool in a thin layer around the lower part of the flask. If difficulty is still experienced in dissolving the material, a rounded glass rod will be found convenient for breaking up the undissolved particles. Not more than one-half of the total amount of naphtha required should be used until the sample is entirely broken up. The balance of the 100 cu cm is then added, and the flask is twirled a moment in order to mix the contents thoroly, after which it is corked and set aside for 30 min. In making the filtration the utmost care should be exercised to avoid stirring up any of the precipitate, in order that the filter may not be clogged and that the first decantation may be as complete as possible. The sides of the flask should then be quickly washed down with naphtha, and, when the crucible has drained the bulk of insoluble matter is brought upon the felt. Suction may be applied when the filtration by gravity almost ceases, but should be used sparingly, as it tends to clog the filter by packing the precipitate too tightly. The material on the felt should never be allowed to run entirely dry until the washing is completed, as shown by the colorless filtrate. When considerable insoluble matter adheres to the flask, no attempt should be made to remove it completely. In such cases the adhering material is merely washed until free from soluble matter, and the flask is dried with the crucible at 100° C (212° F) for about 1 hr, after which it is cooled and weighed. The percentage of bitumen insoluble is reported upon the basis of total bitumen taken as 100. The difference between the material insoluble in carbon disulphide and in the naphtha is the bitumen insoluble in the latter. Thus, if in a certain instance it is found that the material insoluble in carbon disulphide amounts to 1% and that 10.9% is insoluble in naphtha, the percentage of bitumen insoluble would be calculated as follows:

$$\frac{\text{BITUMEN INSOLUBLE IN NAPHTHA}}{\text{TOTAL BITUMEN}} = \frac{10.9 - 1}{100 - 1} = \frac{9.9}{99} = 10\%$$

Value of Naphtha Insoluble Bitumen Determination. While the class of bodies known as asphaltenes in petroleum and asphalt products are of variable nature, it may be said that in general they tend to give body and consistency as well as cementitiousness to the materials in which they occur. Thus, the native asphalts carry a high percentage of asphaltenes while the fluid native bitumens or petroleums carry a relatively low percentage. Paraffin petroleums contain less than asphaltic petroleums, and petroleum distillates, which possess no cementitiousness, contain none at all. Upon distillation of a petroleum the asphaltenes tend to concentrate in the residuum, and under certain conditions new asphaltenes are actually formed. The blowing process, by causing what is known as nucleus condensation of certain of the lighter hydrocarbons, forms asphaltenes which are directly responsible for the gradual change of the fluid to a semisolid or a solid.

Irrespective of their method of manufacture, asphalt cements of a given penetration at 25° C (77° F) usually carry asphaltenes within comparatively narrow percentage limits and at least for a given type of asphalt cement the penetration is found to decrease as the percentage of asphaltenes increases. The percentage of asphaltenes is usually additive and, for mixtures, may be calculated with reasonable accuracy from the amounts present in the individual constituents of the mixture. In fluxing a hard asphalt to any higher penetration, the amount of flux that will be required will therefore depend to a considerable extent upon the percentage of asphaltenes present in the flux. The higher this percentage the more will be required. Owing to the unavoidable variations to which this determination is subject, specification limitations of the percent of bitumen insoluble in naphtha are necessarily wider than tho a definite chemical compound was the solvent used. The determination is useful as a means of identification in some instances, particularly when considered in connection with other tests. Of the solid native bituminous materials, gilsonite shows a high percentage of asphaltenes, usually over 45%, while the bitumen of grahamite appears to be almost entirely composed of asphaltenes. While the test is not generally applied to tars, it is of interest to note that the heavy refined tars are almost entirely insoluble in light paraffin naphthas.

46. Bitumen Insoluble in Carbon Tetrachloride (Carbenes)

Carbon Tetrachloride is a volatile, non-inflammable liquid which is almost as powerful a solvent for bitumen as carbon disulphide. It is a definite chemical compound having the formula CCl_4. In the presence of some organic matter, especially in direct sunlight, it tends to decompose slowly and to liberate hydrochloric acid, altho under ordinary conditions it is chemically stable. With the bitumen which it first dissolves it may later react to precipitate a small amount of insoluble material. This property must be taken into account in its use as a solvent and a short period of digestion is therefore adopted in order to prevent a determination of more insoluble material than is really present.

Method of Determination. The bitumen in petroleum and asphalt products which is insoluble in carbon tetrachloride is known as carbenes. The determination is conducted in the same general manner and with the same apparatus as described in the second paragraph of Art. 44 under THE ORDINARY FILTRATION METHOD for the determination of total bitumen, except that carbon tetrachloride is employed as a solvent instead of carbon disulphide. The percentage of bitumen insoluble in carbon tetrachloride is reported upon the basis of total bitumen taken as 100. The difference between the material insoluble in carbon disulphide and in carbon tetrachloride is the bitumen insoluble in the latter. The method of calculating and reporting results is therefore the same as described in the second paragraph of Art. 45 under the determination of naphtha insoluble bitumen.

Value of the Carbon Tetrachloride Insoluble Bitumen Determination. The presence of carbenes in petroleum and asphalt products is indicative of unnecessarily high temperatures in their production. Most carefully prepared petroleum residuums are as completely soluble in carbon tetrachloride as in carbon disulphide. Incipient cracking due to local overheating or prolonged exposure to high temperatures is indicated by the presence of carbenes altho no coke or organic material insoluble in carbon disulphide may have been formed. Where carbenes in petroleum residuums are accompanied by an appreciable amount of organic matter insoluble in

carbon disulphide, indications point strongly to injury of the material by decomposition of some of the hydrocarbons present. Some native asphalts, such as the Trinidad and Cuban products, are slightly more soluble in carbon tetrachloride than in carbon disulphide, while others that have been produced in nature at relatively high temperatures show appreciable quantities of carbenes. Grahamite in particular may show as high as 60 or 70% of carbenes. With the exception of grahamite, however, the percentage of carbenes in most petroleum and asphalt products for use in highway engineering is commonly specified as less than 0.5%. There is no direct relation which may be expressed between the percentage of carbenes and other physical and chemical properties of a material. Thus, a fluid petroleum residuum carelessly manufactured may contain a relatively large amount, while a solid residuum carefully prepared from the same petroleum may be entirely soluble in carbon tetrachloride. All distillates produced by the fractional distillation of bituminous materials are completely soluble in this solvent. As a rule, tars are not as soluble in carbon tetrachloride as in carbon disulphide, but the difference in solubility appears to bear no relation to the amount of free carbon which is present in the tar. In routine examination of tars carbon tetrachloride is not employed as a solvent and the term carbenes is therefore confined to constituents in petroleum and asphalt products.

47. Fixed Carbon

Method of Determination. The fixed carbon determination is a purely arbitrary test for bituminous materials which has been borrowed from the ordinary methods of coal analysis. In 1911 the Am. Soc. Test. Mat. adopted a "Provisional Method for the Determination of Residual Coke in Bituminous Compounds." This method, as described in somewhat more detail by Hubbard and Reeve (25b) is as follows. The determination is made in accordance with the method recommended in 1899 by the Com. on Coal Analysis, Am. Chem. Soc. (12). The apparatus is illustrated in Fig. 44. One gram of the material is placed in a platinum crucible weighing from 20 to 30 g and having a tightly fitting cover. It is then heated for 7 min over the full flame of a Bunsen burner, as shown in Fig. 44. The crucible should be supported on a platinum triangle with the bottom from 6 to 8 cm above the top of the burner. The flame should be fully 20 cm high when burning freely, and the determination should be made in a place free from drafts. The upper surface of the cover should burn clear, but the under surface should remain covered with carbon, excepting in the case of some of the more fluid bituminous materials, when the under surface of the cover may be quite clean. The crucible is removed to a desiccator and when cool is weighed, after which the cover is removed, and the crucible is placed in an inclined position over the Bunsen burner and ignited until nothing but ash remains. Any carbon deposited on the cover is also burned off. The weight of ash remaining is deducted from the weight of the residue after the first ignition of the sample. This gives the weight of the so-called fixed or residual carbon, which is calculated on a basis of the total weight of the sample, exclusive of mineral matter. If the presence

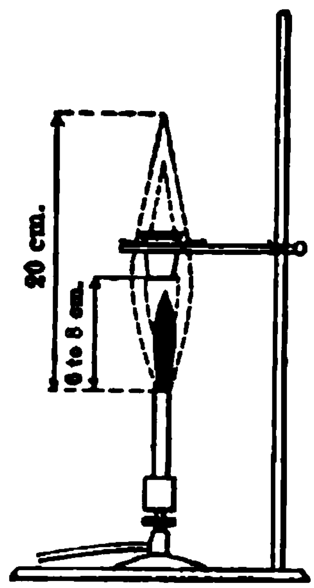

Fig. 44. Apparatus for Determining Fixed Carbon

of a carbonate mineral is suspected, the percentage of mineral matter may be most accurately obtained by treating the ash with a few drops of ammonium carbonate solution, drying at 100° C (212° F), then heating for a few minutes at a dull red heat, cooling and weighing. An excellent form of crucible for this test is shown in the illustration. It has a cover with a flange 4 mm wide, fitting tightly over the outside of the crucible, and weighs complete about 25 g. Owing to sudden expansion in burning some of the more fluid bitumens, it is well to hold the cover down with the end of the tongs until the most volatile products have burned off. This method has been recommended by the Spec. Com. Mat. Road Cons., Am. Soc. C. E. (13) except with regard to the method of heating, which is specified as follows: " The crucible and its contents shall be heated, first gently and then more severely, until no smoke or flame shall issue between the crucible and the lid. It shall then be placed in the full flame of a Bunsen burner for 7 min."

Value of Fixed Carbon Determination. To be of any real value except for the original operator, the fixed carbon determination should be made exactly as described in the preceding paragraph. It is not an exceedingly accurate test and any attempt at variation in the method of heating or other conditions specified will often greatly affect the results obtained. When properly made the fixed carbo test may serve as a means of identifying the type of petroleum from which a fluid or semisolid residuum has been manufactured. Par ffin petroleums and all p:troleum distillates yield little or no fixed carbon. Asphaltic petroleums and their residual products always yield fixed carbon but in varying amounts, according to their origin or method of manufacture. For a given viscosity, float test or penetration, blown petroleums show a very low percentage of fixed carbon, and straight distilled Mexican petroleum residuums an unusually high percentage. For any type of petroleum residuum fixed carbon increases as distillation progresses. It is therefore accompanied by increase in specific gravity, percentage of asphaltenes, viscosity and float test and decrease in penetration. Native asphalts usually yield from 11 to 15% of fixed carbon, altho the harder varieties sometimes run considerably higher, and in the case of grahamite may reach 50% or over. The test is seldom applied to tars or tar products, owing to the presence of free carbon which interferes with the determination. In interpreting the fixed carbon determination it should be remembered that the fixed carbon is actually produced from the material by destructive distillation and does not exist as such in the original material. It is therefore quite distinct from free carbon, which if determined to exist at all is actually present in the original material and is merely separated from the other constituents by means of a solvent.

48. Paraffin Scale

Method of Determination. No very accurate method has as yet been devised for determining the percentage of paraffin scale in petroleum and asphalt products. Most methods require that the material be first destructively distilled and the paraffin scale then recovered from the distillate. Slight variations in method and rate of distillation cause wide variations in results and it appears likely that solid paraffins may be both destroyed and formed under different conditions of distillation. The method as commonly used is as follows. One hundred grams of the material is first weighed into a tared iron retort of about 8 oz capacity. It is then distilled as rapidly as possible without foaming over until only a dry coke residue remains in the retort. The distillate is caught in a 150-cu cm Erlenmeyer flask, the weight

of which has been ascertained. During the early stages of distillation a cold, damp towel wrapped around the stem of the retort will serve to condense the distillate. After high temperatures have been reached, this towel may be removed. When the distillation is completed, the distillate is allowed to cool to room temperature and is then weighed in the flask. This weight minus that of the flask gives the weight of the total distillate. Five grams of the well-mixed distillate are then weighed into a 100-cu cm Erlenmeyer flask and mixed with 25 cu cm of Squibb's ether. Twenty-five cu cm of Squibb's absolute alcohol is then added, after which the flask is packed closely in a freezing mixture of finely crushed ice and salt maintained at -18° C (-0.4° F). After remaining 30 min in this mixture, the solution is quickly filtered thru a No. 575 C. S. & S. 9 cm hardened filter paper placed in a glass funnel, which is packed in a freezing mixture, as shown in Fig. 45. A vacuum should be employed to hasten filtration. The freezing-mixture reservoir shown by *b* may be made by cutting in half a round glass bottle measuring approximately 120 mm in diameter and using the upper half in an inverted position. Any precipitate remaining on the paper should be washed until free from oil with about 50 cu cm of a 1 to 1 mixture of Squibb's ether and absolute alcohol cooled to -18° C (-0.4° F). After the paper has been sucked dry, it should be removed from the funnel and the adhering paraffin scale should be scraped off into a weighed crystallizing dish and dried on a steam bath. The dish and contents should then be cooled in a desiccator and weighed. The weight of the paraffin scale so obtained divided by the weight of the distillate taken and multiplied by the percentage of the total distillate obtained from the original sample equals the percentage of the paraffin scale.

Value of Paraffin Scale Determination. Owing to the fact that the paraffin scale determination is subject to wide variations, it is of doubtful value except as an approximate quantitative test for the purpose of identification. By some the presence of solid paraffins in a bituminous material for use in highway engineering is believed to be undesirable. While it is true that those petroleum products in which paraffin hydrocarbons greatly predominate are unsuited for use as cementing mediums and while a high percentage of liquid paraffin hydrocarbons is often indicated by the presence of an appreciable amount of paraffin scale, it does not follow that the latter are themselves entirely undesirable constituents. In fact, if the material in which they occur possesses the requisite degree of cementitiousness, the presence of solid paraffins may make the material more chemically stable than it otherwise would be.

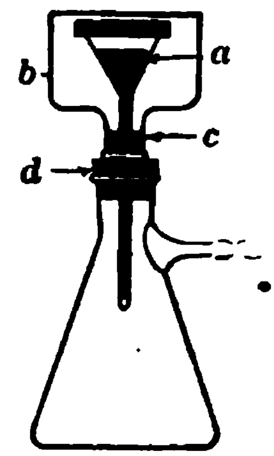

Fig. 45. Apparatus for Determining Paraffin Scale

There appears to be a general tendency to eliminate the paraffin scale clause in specifications for bituminous materials for the reasons above stated. Most asphaltic petroleums and native asphalts contain only traces of paraffin scale while the semiasphaltic type show comparatively small amounts.

SPECIFICATIONS FOR BITUMINOUS MATERIALS

49. Factors Governing Specifications

Value of Tests. Tests of both physical and chemical properties of bituminous materials serve two main purposes: (1) As a matter of investiga-

tion, they constitute a record of the characteristics of the material examined; and (2) when considered in connection with the behavior of a material in use, they serve as a guide for the selection of such material for future use. In the matter of investigation it is often highly desirable that the greatest possible number and variety of tests be applied to a material of construction, as by this means the most complete record of its characteristics is obtained. After considerable data of this sort have been secured on many lots of the same material, it is not as a rule necessary to make use of all of these tests in selecting such material for future use. Certain inherent and peculiar characteristics as determined by tests are, however, of value in the matter of selection, and such characteristics, when governed by quantitative limits, are made the basis of specification for that material. Individual tests as required by specifications for bituminous materials may serve one or more of the three following purposes: (1) They may directly indicate the suitability for a given use of the material specified; (2) they may serve as a means of identifying the source of a material or even the material itself; (3) they may serve to control uniformity in the preparation or manufacture of a material. The first of these purposes is undoubtedly the most important, but it is only partly accomplished by a comparatively few tests. As examples may be mentioned tests of consistency, such as viscosity, the float test, and the penetration test. These tests can only be of maximum value, however, when applied to a specific type of bituminous material and when considered in connection with other tests, which by themselves may not directly indicate suitability. The identification of a bituminous material may be indicated by a number of tests, such as specific gravity, melting point, solubility in carbon disulphide and fixed carbon. The specific gravity determination is perhaps the most important test of identity and this is particularly true when it is considered in connection with the consistency of a material and one or more of the other tests enumerated. Control of uniformity in the preparation or manufacture of bituminous materials is secured by the tests for consistency in connection with melting point, flash point, volatilization, distillation, solubility in paraffin naphtha, and solubility in carbon tetrachloride. Practically all of the other tests may also be made to serve this end. No one by itself will, however, necessarily accomplish this purpose, no matter how close the test limits are drawn. This is mainly due to the fact that products of innumerably varied and complex characteristics may be produced from a given crude material by modifying the method of manufacture.

The Interrelationship of Tests, aside from their individual significance, should be clearly understood for the intelligent interpretation of specifications of bituminous materials, or otherwise the purpose of a specification may be defeated thru conflicting or discriminating clauses which by themselves are apparently above criticism. In all specifications tests are included with at least one and usually two test limits. It is the interrelationship of the limiting factors which is of most importance. The interrelation of any two tests is not a difficult matter to grasp, but when the bearing of three, four, or a dozen tests upon some other has to be considered, the subject becomes complicated and a thoro knowledge of the origin, manufacture and serviceability of the material specified is necessary for an intelligent interpretation of a specification. The prevalent practice of borrowing specifications from other sources, particularly borrowing portions of such specifications and attempting to combine such portions into a single new specification without a knowledge of the interrelationship of tests, is more

than apt to produce a conflict in requirements. This may be illustrated by the following comparatively simple example in which only three factors are considered.

Table XXX.—Comparative Specification Requirements

	A	B	C
Specific gravity 25°/25° C......	0.990–1.010	1.030–1.050	1.030–1.050
Penetration at 25° C, 100 g, 5 sec	50–60	50–60	50–60
Melting point (cube method)....	80° C+	50–60° C	80° C +

It will be noted that the same consistency or penetration requirement is found in all three specifications. Both specifications A and B may be readily met. Thus an asphalt cement of from 50 to 60 penetration may very properly have a specific gravity lying between 0.99 and 1.01 or between 1.03 and 1.05. It may also show a melting point of from 50° to 60° C (122° to 140° F) or not less than 80° C (176° F) as required. If, however, the specific gravity requirement of B and the melting point requirement of A are borrowed to form a new specification C, the combination becomes incompatible from the standpoint of available commercial products. Thus, specification A calls for a blown product while specification B calls for a straight distilled product or one but slightly blown at most. The combination of any two requirements of specification C may readily be met. Two of these combinations exist in the other specifications. The third combination is that of specific gravity and melting point, which if met would greatly lower the penetration limit. From the above it may be seen that as the number of tests to be considered increases their interrelationship may become more and more involved. This subject is further considered in Art. 50.

The Selection of Tests should depend upon the object for which a specification is prepared. A specification should not be encumbered with unnecessary requirements but sufficient requirements should be introduced to insure material which is suitable for the purpose specified and also uniformity of the material. Those tests which are properly specified for bituminous materials most commonly used in highway engineering are as follows:

I. Petroleum and Asphalt Products

1. Specific Gravity of all products.
2. Specific Viscosity of fluids which are too thin for the float test.
3. Float Test of viscous fluids and soft semisolids which are not well adapted for the viscosity or penetration tests.
4. Penetration Test at 25° C, 4° C and 46° C (77°, 39° and 115° F), where possible, for semisolids and solids.
5. Melting Point of the harder semisolids and solids.
6. Flash Point for all products and sometimes the burning point for materials of low flash point.
7. Volatilization Test at 163° C (325° F) of all materials.
8. Consistency of the residues from the volatilization when adapted for the float or penetration test.
9. Total Bitumen in all products.
10. Organic Matter and Inorganic Matter Insoluble in Carbon Disulphide for all products.

11. Bitumen Insoluble or Soluble in 86° B Paraffin Naphtha for all products.

12. Bitumen Insoluble or Soluble in Carbon Tetrachloride for all products.

13. Fixed Carbon for all products.

II. Tar Products

1. Specific Gravity of all products.
2. Specific Viscosity of fluids which are too thin for the float test.
3. Float Test of viscous fluids and semisolids which are not well adapted for a viscosity test.
4. Distillation Test of all products.
5. Melting Point of the pitch residue from distillation test.
6. Dimethyl Sulphate Test in case of mixtures of tar and petroleum or asphalt products.
7. Total Bitumen in all products.
8. Free Carbon or Organic Matter Insoluble in Carbon Disulphide for all products.

In some cases it may be advisable to omit certain of these tests or to include others. In addition to the above it is common practice to insert a clause in specifications for bituminous materials which have to be heated before use that they shall be free from water and shall not foam when heated to a temperature somewhat higher than that at which they are likely to be heated during their use. In specifications for bituminous aggregates the character and grading of the mineral matter are often covered. The selection of test limits involves a consideration of many factors which properly form a part of and are included in other sections. Certain principles in connection with the selection of test limits are, however, given in Art. 50.

50. Illustrative Specifications

Types of Specifications. There are two general types of specifications for bituminous materials: Close or discriminative specifications and open specifications. The latter type may be divided into two classes: blanket specifications and alternate type specifications. Close specifications are designed to secure a given type and grade of bituminous material to the exclusion of all others, whether suitable or unsuitable for the purpose specified. Their use tends to restrict and often absolutely prevents competition. The result is therefore unnecessarily high prices. Blanket specifications are designed to secure unlimited competition by means of covering, in a single specification, all types and grades of material which may be suitable for the purpose specified. In attempting to do this, however, test limits are necessarily stretched to such a point that unsuitable materials are also covered and in any event certainty of uniformity in supply is lost. Alternate type specifications are designed to strike a happy mean between the closed and blanket types of specification. They are in effect a combination of the two. They consist of a number of more or less close specifications for the various types of materials suitable and equivalent in value for the purpose specified, the selection of any particular specification being optional with the bidder. Fair competition is thus secured without sacrificing the prime requisites of suitability and uniformity. Examples of close, alternate type, and blanket specifications, in the order named, are given in the following paragraphs for the purpose of illustrating the principles

involved. Typical specifications for bituminous materials for use in the treatment and construction of the different types of roads and pavements are given in other Sections.

Close Specifications vary greatly in character according to their method of preparation. They may be obviously discriminative by actually naming the type of material required or they may be indirectly discriminative by so fixing test limits that they may only be met by the type of material required, altho that type is not actually named. Discriminative tests and specifications are perfectly proper and often desirable if used in the right way, but their significance should be clearly apparent and they should not be put forward as open specifications. When a given type of bituminous material has a single characteristic property which distinguishes it from other types, test limitations of this property may be so drawn as to make the specification discriminative. The status of such specifications is not usually difficult to ascertain. Thus a specification for a refined asphalt which calls for some 35% of a flesh pink ash as surely indicates Trinidad asphalt as tho the words "Trinidad Asphalt" were included in the specification. Discrimination is, however, sometimes secured by the use of a combination of two or more test limitations, the significance of which is only apparent under the close scrutiny of one who has an intimate and comprehensive knowledge of all types of bituminous materials. Specifications of this class may, as a whole, absolutely eliminate competition, altho no single clause in the specification could be criticized from this standpoint. Some close specifications are less close than others. Thus a specification for an oil asphalt may cover oil asphalt which can be commercially prepared from a number of crude petroleums. It will, however, eliminate native asphalt products and tar products which are equally well adapted for the purpose specified. On the other hand, a properly prepared tar specification will eliminate all petroleum and asphalt products and is therefore a more or less close specification. The following isolated specification serves as an example of the close type, primarily prepared for a fluxed Bermudez asphalt for bituminous macadam construction under certain conditions. It also illustrates an approved form of specifying test limits.

Asphalt Cement Specifications

1. The asphalt cement shall be homogeneous, free from water and shall not foam when heated to 177° C (350° F).

2. It shall show a flash point of not less than 163° C (325° F) when tested in the New York State Board of Health Closed Oil Tester.

3. Its specific gravity, at a temperature of 25° C (77° F) shall be not less than 1.035 nor more than 1.060.

4. When tested with a standard No. 2 needle, by means of a standard penetrometer, it shall show penetrations within the following limits for the conditions stated, the penetrations being expressed in hundredths of a centimenter; 100 g load, 5 sec at 25° C (77° F) from 130 to 160; 200 g load, 1 min at 4° C (39° F), not less than 30.

5. When tested by means of the New York Testing Laboratory Float Apparatus, the float shall not sink in water maintained at 66° C (150° F) in less than 120 sec nor more than 180 sec.

6. When 50 g of the material is maintained at a uniform temperature of 163° C (325° F) for 5 hr in an open cylindrical tin dish 2¼ in in diameter, with vertical sides measuring approximately 1½ in in depth, the loss in weight shall not exceed 3.0% of the original weight of the sample. The penetration of the residue when tested as described in clause 4 with a standard No. 2 needle under a load of 100 g, for 5 sec at 25° C (77° F) shall be not less than one-half the penetration of the original material tested under the same conditions.

7. Its bitumen as determined by its solubility in chemically pure carbon disulphide at room temperature shall be not less than 94.0% nor more than 98.0%.

8. It shall be soluble in chemically pure carbon tetrachloride at room temperature to the extent of not less than 98.5% of its bitumen as determined by clause 7.

9. It shall be soluble in 86° to 88° B paraffin naphtha, of which at least 85.0% distills between 35° and 65° C (95° and 149° F) to the extent of not less than 75.0%, nor more than 85.0% of its bitumen as determined by clause 7.

10. It shall yield not less than 11.0% nor more than 14.0% of fixed carbon.

11. Upon ignition it shall yield not less than 1.0 % nor more than 3% of ash.

From the above it is evident that clauses 3, 4, 5, 6, 9 and 11 eliminate all tar products. The combination of clauses 3 and 4 eliminates blown asphalts, and clauses 7 and 11 eliminate all suitable straight distilled petroleum residuums. Such residuums might of course be doctored up to meet the specification limits but this would hardly be commercially practicable for the existing types of available materials. Following is given, for the purpose of comparison, a typical specification of a refined tar suitable for the same purpose.

Refined Tar Specifications

1. The refined tar shall be homogeneous, free from water, and shall not foam when heated to 121° C (250° F).

2. Its specific gravity at a temperature of 25° C (77° F) shall be not less than 1.150 nor more than 1.200.

3. When tested by means of the New York Testing Laboratory Float Apparatus, the float shall not sink in water maintained at 50° C (122° F) in less than 120 nor more than 150 sec.

4. Its bitumen as determined by its solubility in chemically pure carbon disulphide at room temperature shall be not less than 95.0%, and it shall show not more than 0.2% ash upon ignition of the material insoluble in carbon disulphide.

5. When distilled according to the tentative method recommended by Committee D-4 of the Am. Soc. Test. Mat. in 1911, it shall yield not more than 0.5% distillate at a temperature lower than 170° C (338° F); not more than 12.0% shall distill below 270° C (518° F), and not more than 25.0% shall distill below 300° C (572° F).

6. The total distillate from the test made in accordance with clause 5 shall have a specific gravity at a temperature of 25° C (77° F) of not less than 0.980 nor more than 1.020.

7. The melting point, as determined in water, of the pitch residue remaining after distillation to 300° C (572° F) in accordance with the test described in clause 5 shall be not more than 75° C (167° F).

It will be noted that this specification is entirely different from that for the asphalt cement. The combination of clauses 2, 3 and 4 eliminates all petroleum and asphalt products, and the combination of clauses 3, 4 and 6 practically eliminates all refined coal tars. The specification is therefore close and is limited almost exclusively to refined water-gas tars.

Alternate Type Specifications. While either of the specifications given in the preceding paragraph if used alone would greatly limit competition, it is evident that competition would be considerably increased if the two specifications were made optional and for the work specified the bidder were allowed to furnish material which conformed to either one that he might select. Moreover, after such selection he would be obliged to furnish reasonably uniform material owing to the rather close test limits specified. Unrestricted competition could be secured by using a sufficient number of specifications to cover all of the available types and grades of material suitable for the purpose specified. Thus, a specification for refined coal tar, a specification for a blown petroleum, and two or more specifications for the different types of petroleum residuums could be made alter-

native with the above to the advantage of fair competition but without sacrificing suitability or uniformity. Use of the alternate type specification is growing rapidly and promises to supersede that of the older close specification and the unscientific blanket specification. Numerous examples of alternate type specifications for bituminous materials will be found in those Sections dealing with the different types of bituminous pavements.

Blanket Specifications. The use of a single specification covering all types of bituminous materials suitable for a given purpose would be highly desirable if it could be so drawn as to cover the proper grade of each type without admitting unsuitable grades. The ultimate utilization of tests for the purpose of selecting material suitable for a given use makes it necessary, however, that the test limits adopted shall specifically define the material, and that the material thus defined shall have previously proved satisfactory for that particular use. For some classes of materials these points are not difficult to cover. In the case of bituminous materials, however, the matter is complicated by the numerous varieties or types of bituminous materials in common use, and the overlapping characteristics of various grades of these different types. Standards of more or less established test values have been thrown into question by the introduction of new types of bituminous materials which, while similar to or identical in many respects with other better known materials yet differ from them materially in certain physical or chemical properties. This has made it necessary to either modify old standards or to create new standards to be used specifically for the new materials introduced. The latter method is certainly the safer. The frequent impossibility of covering suitable grades of different types of material by a modification of the standard of one to include the other may be illustrated in connection with the relative consistency of a California oil asphalt and a fluxed Bermudez asphalt suitable for the same purpose. Thus, for a certain type of bituminous concrete pavement under a given set of conditions, the proper penetration limits at 25° C (77° F) for the California asphalt may lie between 70 and 90, while the proper penetration limits for the fluxed Bermudez asphalt to be used in exactly the same type of pavement and under the same conditions may be entirely different, perhaps 140 to 160. It is evident that to attempt to cover the penetration limits of both materials under one specification would be useless. In the first place, such test limits as 70 to 160 are so wide as to insure but little uniformity in different lots of the same material, and in the second place, an entirely unsuitable material of one type might be supplied under the maximum test limit of the other type. A finer distinction may be drawn in the differences between asphalt cements produced by the straight distillation of two types of petroleum, Mexican and California. Thus, high fixed carbon in most asphalt cements produced from Mexican petroleums is a distinguishing characteristic. Relatively low fixed carbon in good asphalt cements produced from California petroleums serve to differentiate them from Mexican products. Here, again, the necessity or desirability of different test limits is apparent, for if the amount of fixed carbon yielded by a California asphalt cement was as high as the 16 or 17% often found in Mexican asphalt cements, indications would point very strongly to injury of the former due to excessive temperatures having been employed in the process of manufacture. With regard to widely different types of bituminous materials, such as tars and asphalts, it is generally admitted that a blanket specification is absolutely unsatisfactory. It is also unsatisfactory to attempt to cover low carbon tars and high carbon

tars under a single blanket specification. In general, however, for any given purpose it is possible to cover suitable grades of all types of available tar products by means of two alternate specifications. Available petroleum products suitable for the same purpose may usually be covered by from two to four alternate specifications and available fluxed native asphalts by two or three alternate specifications. The alternate type plan involves more work, and, until the principles involved are clearly understood, appears to be much more complicated than the blanket specification. As at best the latter is unsafe, if not absolutely worthless, the extra work involved by the former is undoubtedly worth while. Aside from actual suitability of a material, the matter of uniformity of supply is extremely important, as uniform work cannot be secured with material which is not uniform in character. As previously stated, the blanket specification is wholly inadequate to insure uniformity.

PURCHASE, TRANSPORTATION, STORAGE AND INSPECTION OF BITUMINOUS MATERIALS

51. Purchase of Bituminous Materials

Volume Basis. Bituminous materials for use in highway engineering may be purchased upon either a volume or weight basis. Both methods have their advantages and disadvantages. In the last analysis the volume of bitumen purchased and used is of most interest to the highway engineer, but there are certain handicaps to the volumetric method which are sometimes difficult to meet. In the first place, containers are seldom completely filled with bituminous materials and the volumes therefore have to be calculated or estimated. This is not a difficult matter when material is supplied in bulk, as in the case of tank car shipments; but when smaller containers are used, such as barrels and drums, their variation in shape and size may be so great that a determination of the true volume of a given shipment is no simple matter. It is common practice, however, to purchase fluid and soft semisolid materials by the gallon. When this is done the gallon is usually considered at 15.5° C (60° F), and if the material is delivered hot an arbitrary correction for expansion is made as described in Art. 34. This is reasonably satisfactory for materials which are practically pure bitumen, but if it is desired to purchase the material upon a bitumen basis, that is, to pay only for the bitumen delivered, exclusive of all extraneous matter, the volumetric method is not satisfactory as the extraneous matter is not determined by volume but by weight. In comparing prices for bituminous materials, the actual amount of bitumen present in the material is an important factor. It is perfectly evident that gallon for gallon a tar containing 5% free carbon represents more bitumen than one containing 25% free carbon, yet such facts are frequently overlooked.

Weight Basis. The weight basis of purchase is commonly used in connection with the harder semisolid and solid bituminous materials. Weights are of course the same irrespective of temperature changes, and if it is desired to purchase upon the basis of actual weight of bitumen delivered, this may be done by reference to an analysis of the material showing the percentage of bitumen and extraneous material. Asphalts and asphalt cements are thus sometimes purchased and paid for according to the tons of actual bitumen delivered. This is only reasonable as it is evident that a ton of asphalt consisting of practically 100% bitumen will go farther

than a ton of one containing 35% of mineral matter. In other words, 2 tons of the former will be equivalent to about 3 tons of the latter. Carrying this refinement still further, the specific gravity of the pure bitumen should also be considered as a factor in comparing prices, as it is evident that the same weights of bitumens of different specific gravity will represent differences in volume. Such points as these are often neglected altho in a large contract they may often represent considerable monetary value.

52. Transportation and Storage

Tank Cars and Tanks. Fluid bituminous materials ready for use are ordinarily shipped to the consumer in tank cars of from 4000 to 12 000 gal capacity. These tank cars are, as a rule, equipped with steam coils which may be connected from the outside with the boiler of a road roller or tractor in case it is necessary or desirable to heat the material before unloading the tank. Semisolid materials are also sometimes shipped in tank cars, in which case it is very important that the coils be so designed and placed as to insure efficient heating of the entire contents. The older types of steam-heated tank cars are unsuited for the shipment of semisolids but in the most modern types, which are specially designed for the purpose, asphalt cements of very low penetration may be brought to a fluid condition. Tank cars are necessarily subjected to unusual strains and it sometimes happens that leaks will develop in the heating coil. If this occurs and it is necessary to heat the material above 100° C (212° F), serious trouble may result from foaming due to leakage of condensed steam, altho the original material may have been absolutely free from water. For this reason the shipment for long distances in tank cars of semisolid materials which have to be brought to a relatively high temperature before they can be unloaded is not always satisfactory, and the use of tank cars is therefore largely confined to the fluid and rather soft semisolid products which do not have to be highly heated. The tank car method of shipment, while desirable in many ways, is apt to prove expensive unless upon arrival at their destination facilities are at hand for removal of the contents of the tanks within a comparatively short time. It frequently happens that the engineer is not in a position to at once use an entire tank car load of bituminous material upon its arrival. A long spell of rainy weather may, in fact, postpone its use for a number of weeks. This means that the demurrage charges will constitute an appreciable factor in the cost of the material. In addition to the demurrage of $1.00 per day charged by the railroad company, the leasing value of a tank car is stated by Kershaw (26) as being about $1.25 per day. The loss resulting from the detention of a car is considered to fall on the shipper but is actually borne by the consumer, who pays a higher price for the material than would be the case if he were known to have a storage tank available. Kershaw recommends the use of cylindrical storage tanks of about 12 000 gal capacity, measuring approximately 30 ft in length and 8 ft in diameter, set upon steel supports and equipped with steam coils. The tank should be placed so as to give a minimum fall of 2 in in 30 ft toward the outlet, which should be placed as near one end as possible. The arrangement of the steam coils should be such that a coil is placed immediately above or around the opening in the outlet pipe in order to prevent possibility of the outlet becoming blocked by the collection of cold solid material. The main coils should be placed on a cradle as low as possible in the tank, with a maximum distance of ¾ in between the bottom of the coil and the tank. For

the use of heavy materials the outside piping should be steam jacketed. The following cost data is given for the installation of a 12 000 gal storage tank at Greenwich, Conn. This tank was constructed with two compartments, one of which was fitted with steam coils:

Tank, f.o.b. shipping point	$327.96
Freight	52.00
Piping	165.00
Concrete abutments	230.00
Painting	15.00
Extras	5.00
	$794.96

Kershaw further states that " it has not been unusual for towns using from 100 000 to 200 000 gal of oil to pay the railroad company more than $1000 per annum in the form of demurrage, and quotations have been made in favor of the towns equipped with storage, which net a saving of from 2 to 5 mills per gallon."

Barrels and Drums. A very large proportion of the semisolid and solid bituminous materials is shipped to the consumer in barrels or drums. For the harder grades of materials such as refined asphalts, which require fluxing before use, open-head slack barrels are often used. These barrels are clayed on the inside so that, after cutting the hoops, the staves may be stripped from the asphalt with little or no waste. Slack barrels weigh approximately 20 lb and hold from 300 to 400 lb of refined asphalt, depending upon its specific gravity. They are sometimes double-headed, but in storage should always be placed on end. If stored on their sides they are apt to cave in, no matter how hard the asphalt may be, as they are not designed to withstand the unequalized strains produced by the slow flow or deformation of the asphalt from its normal position at the time of filling. Double-head tight barrels of approximately 50 gal capacity but sometimes varying from 40 to 60 gal capacity are largely used for semisolid and viscous bituminous materials. Such barrels may weigh from 60 to 70 lb each and represent approximately 15% of the gross weight of the shipment. They are much stouter than the slack barrels but should be stored on end. Except in the case of fluid products, it is common practice to destroy these barrels when removing their contents, altho the actual value charged for each barrel amounts to two cents or over per gallon of bituminous material. It is sometimes possible to save the barrel with the exception of one head. If this is done wastage thru adhesion of a portion of the material to the inside of the barrel becomes a factor to be considered as well as the loss of time in draining the contents. These losses, together with the return haulage and freight, and the difference in value allowed by the manufacturer for the empty barrel may practically offset the loss of the barrel itself if the hoops are split and the barrel and contents dropt into the melting kettle from which the staves may be removed, as they float to the surface, and used as fuel. Thin sheet metal drums are used to a considerable extent in place of barrels for the transportation of semisolid bituminous materials. These drums are light weight and hold from 375 to 525 lb of material. They are made with both single and double heads. They are considerably cheaper than tight barrels but possess the disadvantage of rusting out upon prolonged storage in the open. They are also readily dented and sometimes punctured during loading and unloading, in which case it is practically impossible to repair them and if not soon emptied the bituminous material gradually leaks out to the level of

the puncture. They cannot well be stacked without being slowly pressed out of shape and bursting. In emptying they are usually cut with a hatchet and the drum and contents thrown together into the melting kettle. When removed from the kettle their ultimate disposal is sometimes a problem to the consumer, as they cannot be destroyed. They possess certain advantages, however, which largely offset their disadvantages. If carefully handled and stored, wastage of the bituminous material is reduced to a minimum as well as cost of transportation. As they have vertical sides there is less loss of floor space during transportation than is the case with barrels.

53. Inspection of Bituminous Materials

Factors Governing Sampling. The proper sampling of bituminous materials is often neglected thru carelessness or lack of appreciation of the factors which should be considered. Too often a single sample is taken at random from a large consignment of material and the analysis of the sample is considered as representing the entire consignment. Such procedure is apt to prove not only valueless but extremely misleading when an attempt is made to correlate the physical and chemical properties of the material with service results. In the first place, all necessary precautions should be taken to insure that the samples shall truly represent the entire lot of material sampled. This can only be done by taking a number of samples from a lot and checking certain characteristics of the individual samples against each other prior to making a complete examination of the mixed samples. Uniformity is one of the most important facts to be ascertained in connection with a shipment of bituminous material and this can never be determined from the examination of a single sample. It is difficult to formulate definite rules which will cover all conditions that have to be met in sampling the various types and grades of bituminous materials used in highway engineering, but the following fundamental principals should always be observed. (1) Take samples with a view to ascertaining the maximum variations in characteristics which the material may possess. (2) Be sure that sample cans are first scrupulously clean and that, in taking samples, no extraneous matter of any sort is introduced. (3) Immediately after filling, the sample cans should be tightly closed and properly marked for identification. (4) Identification marks should be placed on the sample can itself and not upon the lid unless both can and lid are marked. (5) Samples should be packed for shipment in such manner that leakage of contents or contamination by excelsior, paper, or other packing material during transit is entirely prevented. For ordinary analysis samples of not less than 1 pint (approximately 1 lb) should be taken and it is often preferable that they should be twice this size. For fluid products a rectangular can with small screw top is preferable. For very viscous and soft semisolid products a cylindrical can with a tight-fitting pry lid, such as commonly used for paints, will be found convenient. For the harder semisolid and solid products, a shallow rectangular or cylindrical can with ordinary box lid top is suitable. In marking tin cans a 10% solution of silver nitrate will be found useful. The marking should, however, be allowed to thoroly dry before packing or otherwise it is likely to be obliterated. If such solution is not used, the outside of the can should be scraped so as to present a rough surface upon which a gummed label may be securely attached. This is necessary in order to prevent the label from dropping off after the gum has dried. Samples should be taken in the open, preferably during dry weather, but if taken in rainy weather care should be exercised to prevent water from

being introduced into the sample can. Samples should always be examined prior to the use of the material. They may be taken at the point of shipment or upon arrival of the material at its destination. The former practice is preferable as rejection will then incur no loss in handling and transportation.

Sampling from Tanks. Fluid products may readily be sampled from tanks, but with semisolids and solids the matter is more difficult unless the material is first heated to fluid consistency. When a larger order is placed for continuous delivery, as in state highway work, a storage tank may be filled and reserved by the manufacturer for that particular order. The inspector may then be required to sample the entire bulk of material at one time, prior to loading it for shipment. If this is the case, at least three samples should be taken; the tank sealed both at inlet and outlet, and only unloaded in the presence of the inspector. One sample should be taken from the draw-off near the bottom, one from near the top, and one from the center of the tank. A can or bottle attached to a long stick may be used for taking the last named sample. The sampler should have a sufficiently narrow mouth to be closed by a stopper which may be removed by means of a stout piece of twine when it has been dipped to the proper level or the lid of a wide mouth can may be attached to a heavy wire so that it may be removed when desired. When suitable facilities are at hand, it is always well to thoroly agitate the entire contents of the tank prior to sampling. The contents of tank cars may be sampled either at the point of shipment or delivery, in the same manner as described for storage tanks. If the material is sampled at the point of delivery, however, and is a semisolid or solid, it will usually be necessary to first heat it to fluid consistency. This entails considerable expense as the material will either have to be kept hot during the period of test or again heated before use if the results of examination show it to be satisfactory. The necessity of sampling from different levels is apparent when it is considered that a storage tank may contain the residual contents of a number of stills and even a tank car may be partially filled from the last portion of one still and the difference made up from the contents of another still. When sampling from the draw-off of a tank it is always well to discard or return the first two or three gallons removed in order to avoid sampling material which may have remained in the draw-off pipes from a previous filling.

Sampling from Barrels and Drums. When sampling from small containers, such as barrels or drums, it is advisable to take one sample from every 20 packages and fraction of 20 over 10 in a given shipment. The most satisfactory time to sample is when the material is being run from the still or storage tank into the container, as it is then always fluid and the sample may be obtained with an ordinary tin dipper. If the material has already been placed and stored in barrels or drums prior to sampling, it is quite possible that various lots of different grades of material may have become inadvertently mixed thru careless handling. The containers sampled should therefore be carefully selected with reference to their position in the shipment and the manufacturers' markings which they may carry. These markings should be recorded for every container sampled and used as a means of identification. In no case should two adjacent containers be sampled unless they bear different markings. In the case of double-head barrels, it is good practice to occasionally up-end every other barrel selected and sample from what was the bottom. When the material is in drums or slack barrels some samples should be taken, if possible, 5 or 6 in below the surface. This is advisable because, when a con-

tainer is first filled with hot material considerable contraction takes place upon cooling and after cooling, the container may be topped by running in additional material. It is possible that thru mistake the material used for topping may be of a different grade, and samples taken from the tops will therefore not represent the consignment. Samples of solid products may be chipped out with a hatchet. If any water or dirt is on the surface of the material in the barrel or drum selected for sampling, it should be removed so that the surface is clean and dry. A large sponge will be found useful for this purpose. If the material is too soft to be chipped out, a central portion of the top surface, from 5 to 10 in long and 2 to 4 in wide, may be removed to the desired depth by means of a broad stiff putty knife. A hatchet or small hand axe is often convenient to mark out the portion which is to be removed. The first cut is thrown away and the sample taken from the bottom of the hole by means of the putty knife.

Control Inspection of bituminous materials from the engineering standpoint is necessary at the laboratory, paving plant and on the highway. Upon receipt by the laboratory of a number of samples representing a given consignment, tests for consistency should be made upon each sample and a specific gravity determination on every alternate sample. If these tests check within reasonable limits, the samples are mixed and a complete analysis run on the mixed sample to determine whether the material conforms with specifications. After a consignment has been approved for use, the laboratory then serves as a check upon the plant or highway inspection. The plant inspection of bituminous materials has mainly to do with temperature control, consistency control and regulation of the amount of bituminous material used. All melting and fluxing kettles should be provided with stationary thermometers for determining the temperature of the material at all times. When a tank or kettle of material has been maintained at an elevated temperature for a considerable length of time, the inspector should sample the contents and make a consistency test of the sample to determine whether or not undue hardening has occurred. He should be provided with the necessary equipment and a suitable place for making these tests. He should occasionally forward a sample of bituminous material to the laboratory for check and should superintend and record the use and amount of flux required to soften the material if fluxed products are prepared at the plant. If a heated mineral aggregate is used, he should inspect and control the temperature of such aggregate in order to prevent possible injury to the bituminous material thru its overheating. For this purpose he should be provided with a suitable armored thermometer. He should inspect the measurement and proportioning of the bituminous material with reference to its incorporation with the aggregate and should see that the weighing bucket is frequently tared. He should take occasional samples of the bituminous aggregate and forward same to the laboratory for a check upon the percentage of bitumen and grading. In the case of sheet-asphalt surface mixtures he should make temperature and pat tests upon the samples taken, for his own guidance and check as to whether or not the proper percentage of bitumen is being used. Full details of his duties in this connection will be found in Sect. 17. If at any time it is necessary to change from one type of material to another, he should see that the tanks and kettles are first emptied and scrupulously cleaned in order to prevent mixture of the two. The inspector at the highway should inspect the temperature of the bituminous material or bituminous aggregate as delivered for immediate use. He should see that the

bituminous aggregate is laid to proper thickness and that it is properly compressed. He should cut out occasional sections of the wearing course in the case of fine bituminous aggregate pavements and submit same to the laboratory for density determinations. In case there is no stationary paving plant and the bituminous material is handled directly upon or adjacent to the highway, his duties, according to the type of work done, should be similar to those enumerated for the plant inspector.

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SECTION 13

DUST PREVENTION BY THE USE OF PALLIATIVES

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GENERAL DATA

1. Causes of Dust

The Causes of Dust Formation on street and road surfaces are chiefly from three sources, the wearing of the materials of which they are composed, the deposition of foreign materials upon them from outside sources by the wind, by the wheels of vehicles and by leakage from vehicles, and the excrements of animals. The degree of dust formation depends upon the amount and kind of traffic, the type of roadway surfacing and climatic conditions. On hard, smooth pavements the formation of dust from wear is not excessive and its presence is principally due to the last two causes. On broken stone, gravel and earth roads dust formation is excessive and occurs from all three causes, but principally from the wearing away of the surfaces by the vehicles passing over them. Also the methods and materials used in construction and the condition in which the roadway surfaces are maintained have an important bearing upon the formation of dust. Conditions which have a tendency to confine traffic to a single track on a roadway surface, such as too narrow construction, too much crown, and loose, soft surfaces, will increase the formation of dust. See (5).

The Effective Means of Suppressing the Dust Nuisance are the prevention as far as possible of the formation of dust, the proper and systematic cleaning of the roadway surfaces and the use of palliatives.

The Determination of the Necessity for and the Advisability of Using Dust Palliatives depends upon the type and condition of the roads, the character and amount of traffic using them, and the local conditions bordering them. The selection of the materials for dust prevention best suited to each case depends upon these same considerations, with the addition of that of cost.

2. Selection of Materials

City Streets, generally constructed with hard, smooth pavements, are subjected to extreme amounts of very heavy traffic. Altho frequent and thoro cleaning is the best dust preventive, the use of palliatives is necessary. The only materials which can be used on such surfaces are water and solutions of calcium chloride. On city streets with water-bound broken stone surfaces, in residential districts, or localities where the traffic is not excessive, calcium chloride, waste sulphite liquors, oil emulsions or light oils may be used. Light tars and medium oils may be used where the street can be closed to traffic for a sufficient length of time to allow for their application and covering with sand or stone screenings. More permanent results are obtained with the last mentioned materials. This class of streets, constructed with bituminous surfaces, if proper attention is given to cleaning, seldom requires the use of palliatives. When dust formation occurs from a worn condition, an application of a light material of the same nature as that with which the surface is constructed will usually be effective for a considerable length of time.

Suburban and Town Streets, constructed with water-bound broken stone and gravel surfaces, are subjected to greatly varying amounts and character of traffic, and in the selection of materials these are the chief considerations. The number of materials from which to choose is greater for this class of roads than for any other, and practically all of them may be used, as each is suitable to some conditions existing thereon. On residential streets, which carry no thru traffic, calcium chloride, waste sulphite liquors, oil emulsions or light oils may be successfully used; on streets carrying a large amount of thru automobile traffic and a small amount of heavy horse-drawn vehicle traffic, the light or medium oils or light tars should be used; on business streets, calcium chloride, waste sulphite liquors, oil emulsions or light oils are preferable, as the difficulty of applying and protecting the medium oils and light tars practically eliminates them. In all cases where salt solutions and emulsions are to be used, a water supply must be readily available. Tars are not suitable for use on gravel surfaces unless the gravel is of a clean, sandy nature with a small percentage of clay. On bituminous surfaces the same methods should be followed as recommended for city streets.

Country Roads are of two classes, improved roads with broken stone or gravel surfaces, and common earth roads roughly graded and shaped up with the native soil. The first class may be considered as hard roads and the second as soft roads. They are generally subjected to varying amounts of mixed traffic. On the hard road surfaces carrying a considerable amount of about equally divided mixed traffic, tars should be used; on hard road surfaces carrying principally automobile traffic, medium oils or light tars are equally satisfactory; on soft earth roads, on account of the fact that they will generally break up during certain seasons of the year, the use of the heavier materials is inadvisable, and the light oils are about the only kind suitable. The use of salt solutions and emulsions on country roads is generally impracticable, because of the difficulty of obtaining a water supply. Bituminous surfaces should be treated as previously described.

Boulevards and Park Highways are usually subjected to only pleasure vehicle traffic, chiefly automobiles. On the shaded wood roads which carry a small amount of this class of traffic, and which are usually constructed with water-bound broken stone or gravel surfaces, good results

may be obtained by the use of calcium chloride, oil emulsions and light oils. Medium oils and light tars are, however, more durable. The heavily traveled boulevards and park highways, generally having bituminous surfaces, either by being so constructed or by development from the original surface by the application of a carpet of heavy bituminous material, seldom show any dust formation, and when it does occur a retreatment with like material as previously described should be made.

MATERIALS AND METHODS OF APPLICATION

3. Water

Value as Dust Palliative. Water has always been considered an effective dust palliative, and previous to the advent of the swiftly moving motor vehicle was about the only material used for this purpose. The motor vehicle traffic has so changed conditions and requirements that water alone is neither effective nor economical for use on many types of road surfaces. It is generally used on the so-called permanent pavements, such as granite block, wood block, brick and sheet-asphalt, both in the process of cleaning and for sprinkling between cleanings to lay the dust. Its use on broken stone, gravel and earth road surfaces does not give satisfactory results. Its effects vary with the temperature and weather conditions and are of short duration in dry, hot weather, when the conditions are worst. It requires frequent applications during each day and it is difficult to regulate its application so as to obtain uniform results. Considering the benefits derived from its use, the cost is excessive. Altho a certain amount of water on a water-bound broken stone or gravel road is beneficial, an excessive amount will cause muddy and slippery conditions and damage to the surface. Where the traffic consists principally of automobiles, the use of water has a tendency to aid the destruction rather than the preservation of the road surface.

Efficiency and Economy of Watering. Whinery (31) states that "The best known and longest used method of making and keeping streets and roads dustless is by sprinkling with water. At the same time it may be said to be the least developed process, as far as scientific study and application are concerned. Accurate and extended observations on the effect of sprinkling roads and streets, the cost of the process, the quantity of water required, the best and most efficient method of applying the water, and other pertinent matters have either not been made or the results have not been published. If any one doubts this, let him attempt to obtain, from the scanty literature relating to the subject, reliable and consistent data on any of these points.

"Municipal engineers seem to have always looked on street sprinkling as an everyday, matter-of-course operation, not worth serious attention and study, and not susceptible of much improvement in efficiency and economy. It is safe to say that no other municipal function or process receives so little intelligent attention and supervision.

"The cost of efficient street sprinkling is difficult to determine satisfactorily from the data available. Where referred to at all in municipal reports, the necessary conditions to enable one to deduce reliable figures of unit cost are usually wanting. These reports indicate that the cost, exclusive of water, ranges from less than 1 cent to 3½ cents per sq yd for the watering season, which usually extends from May 1st to Oct. 15th. The number of square yards sprinkled once is seldom given, and as the number of times sprinkled per day or per season varies greatly in different cities, and on different streets in the same city, and as there are other varying conditions to be taken into account, it is not possible to get at the basic unit cost from the available records. It is practicable, of course, to estimate the theoretical cost very closely, but such estimates are less satisfactory than actual data from experience.

"The statistics available seem to indicate that, exclusive of the cost of the water,

the average cost per square yard per season is about 2 cents. The quantity of water reported as used is as variable as the cost of applying it. The figures vary from 20 to 70 gal per sq yd per season. Probably 45 gal is a fair average, and, at $90 per 1 000 000 gal, the cost for water per square yard per season would be about 0.4 cent, making the average total cost less than 2.5 cents per sq yd per season. In Boston, where the accounts are now kept with care, the quantity of water used in 1909 was less than 25 gal, and the total cost 2.1 cents per sq yd per season. In the suburban City of East Orange, for the same year, these figures were, respectively, 58 gal and 2.82 cents, including the cost of water.

"As to cost, there is good reason to believe that with careful, intelligent, and economical management, including the restriction of the quantity of water used to that actually necessary, it would not much exceed the average cost of the work as now unsatisfactorily done. Ordinarily, at least, it should not exceed 3 cents per sq yd per season, and this figure may be safely used for comparison with other methods."

Marker (24) states that "It is a well-known fact that water is very effective in allaying dust. When properly applied to a stone road it has some value in preserving the surface, by aiding the stone in retaining its cementing properties. Before repeatedly applying water to a road, the surface should be cleaned, and then the complaint will not be made that the water causes a muddy surface. Water is not only used to allay dust on earth, gravel and macadam surfaces, but also to remove the fine dust which accumulates on such surfaces as brick, sheet-asphalt, wood block, etc, between cleanings. In this latter case it may be the most practical means of preventing dust after reasonable care has been taken in cleaning a street. Generally, from an economic point of view, dust prevention by the use of water on gravel and macadam roads is not very satisfactory, when compared with the use of other means of dust prevention. On hot, dry days, it evaporates very rapidly, and hence its effects are of very short duration. Consequently, on such days when the dust is the most annoying, it is almost impossible, at least impracticable, to keep the surface moist by this means. For rural roads the method of preventing dust by watering is entirely impracticable."

Blanchard (10b) states that "One way to satisfactorily prevent dust on pavements, which are subjected to excessive horse-drawn vehicle traffic, consists of removing street refuse by hand sweeping, during the day; mechanical sweeping of the streets at night; and finally flushing with water to cleanse the surface of the pavement. Periodically watering of pavements to lay dust thruout the day is fundamentally wrong, as the fine dust which necessitates sprinkling should have been removed."

The Usual Method of Applying Water to roadway surfaces for the purposes of dust laying is by means of horse-drawn carts equipped with sprinkling devices in two forms, one discharging the water vertically, and the other horizontally. For use on the hard pavements of city streets the vertically discharging sprinkler valves are preferable, as they are more easily manipulated in operation so as to avoid damage to pedestrians, and the action of the water tends to flush the dust to the gutters without damage to these roadway surfaces. The action of this type of valve on water-bound broken stone or gravel surfaces has a destructive effect, and the valves with horizontal discharge should always be used. The carts consist of a cylindrical tank, either of wood or steel, mounted horizontally on a four-wheel running gear. The capacities of these tanks vary from 350 to 1000 gal, and that usually used has a capacity of about 600 gal. Motor-driven sprinkling trucks are also used for this purpose. The cost of a 600-gal horse-drawn sprinkling cart is about $350.

Amount of Water per Square Yard. Essex (15) states "that each water van, 380 gal effective, should distribute 24 loads per day over 6 miles of roadway watered once, namely, 9000 gal to 88 000 super yd of carriageway, or 10 yd to the gal. At that time the writer was getting only 17 vanloads per day, and in consequence advocated the insertion of a new clause in the street watering contract to ensure the distribution of the 9000 gal required daily. The effect of the new clause was to increase the tender prices for cartage by 1s. 6d. (36.5 cents) per day for supervision; but even then there was an actual saving in distribution in 1913 compared with 1910 of 2.56d. (5.2 cents) per 1000 gal, or £193 ($939.13) for the season. The

Warwick sprinkler, a type which has been largely supplied to municipal authorities, is sent out with a variable spread, by which the carman can empty his van in 6, 4½ or 3 min respectively, but it will be noticed that to distribute not more than 0.02 in with the fine spread he would have to travel 3½ miles per hr, with a medium spread 6¼ per miles hr, and with the heavy spread at the impossible rate of 9 miles per hr. It is the indiscriminate use of such vans that gives rise to most of the complaints as to excessive watering of carriageways, and if all water vans were fitted with a time recorder the head of a department could see for himself when the men were emptying their vans too quickly. In his district the writer has altered all sprinklers to empty in not less than 9 min, which gives a rate of travel of 2½ miles per hr."

The Essex Time Recorder. "The objective of this recorder is to satisfy the municipal surveyor, or other person responsible for the proper watering of town streets and roads, that each van has distributed a certain number of loads per day, that those loads have been full vanloads, and that the times of traveling to and fro between standposts and roads to be watered has in no case been excessive owing to the unsuitable position of any standpost. The recorder consists of a card rotated once in 12 hr by a simple clockwork arrangement with a float inside the water van partially rotating a rod on the top of the van, to the end of which is attached a flat spring arm carrying a pencil which records on the cards."

The Cost of laying dust by sprinkling with water varies greatly and depends upon the efficiency with which the work is done, the cost of labor and water, and the frequency of sprinkling necessary for the different types of road surfaces. From records available the cost varies from 2½ to 4 cents per sq yd of roadway surface for the season when this method can be employed in the average climate of the United States. For efficient work on broken stone or gravel roads the higher cost is nearest correct.

Cost Data on Sprinkling Streets with Water in Webb City, Mo. (28). "During the 145 days of the season of 1912, 5758 tanks, or 475 496 cu ft of water were sprinkled upon the 30 425 sq yd of surface covered. As the water was paid for at a flat rate of $35 per month, this cost the city $0.034 per 100 cu ft. The number of tanks sprinkled per day varied from 15 to 57, with an average of 46. This gives an average of 0.128 cu ft per sq yd per day. Of the 145 days in the season sprinkling was done on 126, or 87% of the time. The 19 days lost represent actual time when, from rain or other causes, sprinkling was unnecessary. However on some days the route was only covered two or three times instead of the regular four trips that were usually made.

Itemized Costs per Day

	Total for 145 Days	Per Day
Driver, 110 days at $2, 35 days at $1.75	$281.25	$1.9396
Collector, 4% of $958.65	38.35	0.2645
Medicine for team	1.40	0.0095
Shoes for team at $3 per set	17.08	0.1177
Hay and bedding, hay at $9 per ton, straw at $0.10 per bale in barn	50.40	0.3476
Feed, bran at $1.25, chops at $1.60, oats at $0.45 and $0.60 in barn	94.75	0.6534
Repairs and renewals to harness and sprinkler	61.65	0.4252
Receipt books, 2000	5.50	0.0379
Water, 4⅔ months at $35	163.35	1.1266
Interest on investment, 6% of $350 for 1 year, 6% of $560 for 5 months	35.00	0.2414
Depreciation on sprinkler, cost $350, life 10 years, 3% compound, 8.73% of $350	30.56	0.2108
Depreciation on team and harness, value $560, life 8 years, 3% compound, or 11.25% of $560, for 5 months of year	26.25	0.1810
Total	$805.54	$5.555"

Cost Data on Street Sprinkling in Manchester, N. H. (23). "The sprinkling season began April 14 and extends to Nov. 1, 200 days, but for 30% of that time sprinkling is not found necessary. The average cost to the city, then, for 140 days of actual sprinkling, is $10 500. The capacity of the sprinklers is 600 gal. The average number of loads per sprinkler per day, 30.46; total gallons per day, 274 200; average gallons per sprinkler per day, 18 280; average distance traveled per sprinkler per day, 13.37 miles; average distance sprinkled per day, 9.64 miles; average effectiveness per day per sprinkler, 72%; average waste travel per sprinkler per day, 28%; average cost per mile sprinkled (effective work) $0.518; average cost per mile sprinkled (effective work) should be $0.371; average distance sprinkled per load of 600 gal, 1670 ft, or 2.78 ft per gal."

Efficiency of Electric Street Watering Vehicle (8). "The chassis is a 3½-ton one, and is 18 ft 6 in long and 6 ft 9 in wide. The tank, which is cylindrical in shape, has a capacity of 750 gal, and is fitted with sleeve valve sprinklers. The spray operates at the front of the vehicle, this making it easier of control by the driver, as there is no necessity for him to turn his head to see where the water is going. With fast moving vehicles this arrangement is of the utmost importance. There is no force pump provided, as the pressure of water in the cylindrical tank produces a spray sufficient to water a street 7 yd wide. The electric vehicle is capable of doing the work of six horse vans. The following comparison is based on 5½ days' work per week.

Cost of Electric Vehicle per Week

	£.	s.	d.	
Driver's wages	1	15	0	$8.52
Power, 384 units at 1d. (2 cents)	1	12	0	7.79
Depreciation	2	10	0	12.17
Sundries, insurance, oil, etc	0	6	0	1.46
Water, 84 500 gal	2	2	3	10.26
Total	8	5	3	$40.20

Cost of Six Horse-Drawn Watering Vans per Week

	£.	s.	d.	
Six drivers' wages at 29s. ($7.06)	8	14	0	$42.34
Hire of 6 horses at 27s. ($6.57)	8	2	0	39.42
Water, 173 000 gal	4	6	3	20.99
Total	21	2	3"	$102.75

4. Sea-Water

Physical Properties. Sea-water, on account of the fact that it contains a certain amount of hygroscopic salts, which have a tendency to absorb and retain moisture, has been used for dust laying purposes in some coast cities and towns, but not to any great extent. Hubbard (4) states: "It has long been known that certain salts have so great an affinity for water that they are not only capable of retaining moisture for a long time under conditions which would otherwise produce rapid evaporation, but that they are capable of absorbing water from the atmosphere to a great extent. Some of these salts are so hygroscopic that, in a humid atmosphere, they will often completely dissolve in the water which they have absorbed from the air. Salts of this character are termed deliquescent, and it is to a great extent these hygroscopic and deliquescent salts that have been employed as dust preventives. Their chemical action upon certain rock powders may also increase the formation of binding material to some extent, but they are not primarily employed for this purpose. Their principal use is to keep the road surface in a semi-moist condition for a much longer

period than would be possible by the application of a corresponding amount of water only, and the number of sprinklings necessary is therefore greatly reduced. One of these salts, magnesium chloride, $MgCl_2$, occurs to a considerable extent in sea-water. The effect of its presence in the cheaper grades of table salt may be seen in the tendency by the salt to lump in damp weather. This is due to the absorption of water by the small amount of magnesium chloride which remains even after the salt has been purified. On account of the presence of this substance, sea-water has been tried, in a number of favorably situated localities, for the purpose of laying dust. While the number of sprinklings has been somewhat reduced by this means the results have, as a rule, been far from satisfactory, owing to the presence of an excessive amount of common salt, sodium chloride, which is applied at the same time and which has no hygroscopic properties. In extremely dry weather, a hard salty scale is produced on the road, which is very undesirable, and in wet weather the mud contains so much salt that it is injurious to the varnish and iron work on vehicles. This strong salt mud is also apt to cause soreness around the fetlocks of horses."

The Use of Sea-Water in the process of flushing and cleaning pavements is of some advantage, as a portion of the hygroscopic salt remains after the cleaning, which tends to keep the street surface damp for a longer period. Except at locations close by the sea front with special equipment for pumping, or in cities having a separate salt water service for fire purposes, its use is prohibitive on account of excessive cost of loading and transporting. The methods of application are the same as for water and the costs are practically the same.

5. Calcium Chloride

Calcium chloride is a hygroscopic, deliquescent salt obtained as a by-product principally in the manufacture of washing soda by the ammonia process. It may be obtained in a solid or granulated form or in the form of a concentrated solution. The granulated form is the most convenient and economical for use for dust laying purposes, as it can be applied to the road surface in this form by the dry method, or it can be readily dissolved in water to make solutions of the desired strength. By purchasing it in the form of a solution, unnecessary transportation charges are incurred on account of the large percentage of water, which in the strongest solution amounts to about 60%, whereas in the dry form the moisture contained amounts to about 25%.

The Action of Calcium Chloride on the Road Surface is the same as that of the magnesium chloride in sea-water, as it absorbs moisture from the air and maintains the surface in a damp condition for a longer time than pure, fresh water. It produces a clean, odorless condition, which is very desirable in residential and crowded city streets. It has little, if any, bonding properties for broken stone or gravel surfaces, except in so far as it retains the fine material. For this reason, on roads subjected to excessive automobile traffic, altho it is more effective as a dust layer than water, it does not preserve the surface to a much greater extent. One advantage of the use of calcium chloride, especially in dry form, over water is that it can be used during cold weather when water would freeze. Table I shows the freezing point and average cost of various solutions of calcium chloride.

Table I.—Calcium Chloride

Freezing Point of Solution	Specific Gravity of Solution	Percent Granulated Calcium Chloride in Solution	Pounds Granulated Calcium Chloride per 600 Gal Solution	Cost Cart Load 600 Gal at Plant	Cost Sq Yd 300 Gal Covering 2000 Sq Yd
32° F	1.000	0.0	0	.....	....
30	1.020	3.5	177	$1.42	$0.00036
28	1.037	6.1	318	2.54	0.00064
26	1.054	8.7	457	3.66	0.00092
24	1.068	10.8	578	4.62	0.00116
22	1.081	12.8	693	5.54	0.00139
20	1.092	14.4	787	6.29	0.00157
18	1.103	16.0	884	7.07	0.00177
16	1.114	17.6	981	7.85	0.00196
14	1.123	18.9	1065	8.13	0.00213
12	1.132	20.1	1141	8.52	0.00228
10	1.140	21.3	1218	9.74	0.00244
8	1.148	22.4	1288	10.30	0.00257
6	1.156	23.5	1359	10.87	0.00271
4	1.162	24.4	1419	11.35	0.00283
2	1.169	25.3	1483	11.86	0.00296
0	1.175	26.1	1536	12.29	0.00307
−2	1.180	26.8	1584	12.67	0.00317

This material is particularly effective and suitable for use on gravel walks, fair grounds and resorts which are used by large numbers of pedestrians and on private driveways and race courses.

Report of Committee of Judges of the Roads Improvement Association, England, in 1909 and 1910. "We are of the opinion that the results of the tests of calcium chloride applied in granular form by the 'dry' method have shown that it is a very effective dust layer, and, that it is a cheaper and preferable process to that of street watering, which, as now carried out, is undoubtedly very injurious to macadamized roads; that the treatment has the ill effects of causing, during the winter months, an abnormal quantity of sticky mud, a decided tendency to licking up, and a disintegrating action upon the macadam surface."

Application. Calcium chloride is applied to the road surface by either the DRY or WET method and before the application all excessive loose dust should be removed. In the granular form it is shipped in air-tight steel drums containing about 350 lb. When a drum is opened for use the material should be spread as soon as possible, as it will rapidly absorb enough moisture from the air to cause it to fuse and become lumpy. When applied dry it can be spread with shovels or by means of a fertilizer spreader, the latter method being preferable as it can be more evenly distributed. This spreader consists of a trough about 6 ft long mounted on two wheels. The bottom of the trough is perforated, and the size of the openings is regulated by a movable plate controlled by a lever. There is an agitator running the full length of the trough which operates automatically when the apparatus is in motion and prevents the clogging of the openings. For the first application on broken stone or gravel roads about 1 to 1½ lb to the sq yd of surface should be used and for subsequent applications about one half this amount. Each application of the salts should be effective for from 1 to 2 months, depending upon the traffic and weather conditions. In the use of the dry method of application it is advisable that the surface should be in a damp condition, especially if the weather

is hot and dry. It is also necessary to occasionally feed the salt with sprinklings of water in dry weather. The dry method should not be used on hard permanent pavements, as the salt will be washed or swept by traffic into the gutters before it dissolves. When the calcium chloride is applied by the wet method the salt is dissolved in water to the required strength and sprinkled on the road surface with an ordinary watering cart. The solution, as applied, should contain about 1 lb of salt to 1 gal of water and for a first treatment two applications should be made, with an interval of from 1 to 2 weeks between. Subsequent applications should be made as required at intervals of from 3 to 6 weeks, depending upon conditions before mentioned. A heavier application should be made at the center than at the sides of the road. A strong solution may be made or purchased and stored in metal tanks and drawn off into the carts and diluted as required for application. The material can be more rapidly dissolved by employing some form of mechanical agitation or by stirring with a paddle. A good method suggested by Prévost Hubbard is to suspend the salt in a wire net basket near the surface of the water and as the water in contact with the salt soon becomes a concentrated solution which is heavier than the surrounding water, it sinks to the bottom, producing a circulation and allowing fresh water to constantly attack it.

Cost. Calcium chloride can be purchased in the United States at about $13 per ton f. o. b. at points of manufacture. The cost of treating broken-stone and gravel road surfaces with calcium chloride varies from 2 to 4 cents per sq yd for the usual watering season, and the average cost is about 3 cents. The cost is about the same as that of sprinkling with water and the results are much more satisfactory and even.

Cost of Using Calcium Chloride at Watertown, N. Y. (12c). In 1911 calcium chloride was applied dry from a lime spreader. The streets were first swept by hand. The cost of material, including freight and haul, was $2.85 per drum. About 18 700 ft were treated, 20 ft wide, using 100½ drums of calcium chloride at an estimated cost of 1.33 cents per sq yd. On eleven sections treated, average costs per sq yd were: Sweeping, 0.14 cents; hauling and spreading, 0.14 cents; foreman, 0.05 cents. Total cost on 19 sections averaged 1.69 cents per sq yd.

6. Emulsions

Emulsions to be used as dust palliatives usually consist of water with some saponifying agent and an asphaltic or paraffin oil. Tar is sometimes, tho rarely, used. The saponifying agents most commonly used with oils are alkalies such as potash, soda, ammonia, crude carbolic acid and cheap soap solutions. These form a chemical solution which is miscible with the oils, and when spread upon the road surface separates, and the water quickly evaporates, leaving the oil in a thin evenly spread layer. Paraffin oils used for this purpose produce a greasy condition and give only very temporary results, having no binding qualities. Best results are obtained by the use of asphaltic and semi-asphaltic oils, as after a number of applications a considerable amount of asphalt accumulates on the road surface which not only effectively lays the dust, but also serves as a binder for its protection.

Concentrated Emulsions. Oil emulsions in concentrated form may be purchased from the manufacturers and diluted with water in the carts to the desired strength for application, or may be easily and cheaply prepared by the user. Where this type of palliative is to be used to a considerable extent, a mixing plant may be installed at some central location

for the preparation of the emulsion in the concentrated form, from which it is distributed in this form to the various points of use.

Oil for Emulsion. A typical specification for an oil to be used in preparing an emulsion is as follows: Emulsion oil shall be a petroleum, with an asphaltic base, containing not less than 35% of asphalt; it shall be free from sulphurous hydrogen odors; its specific gravity shall be not less than 0.920 at 25° C (77° F); its flash point not lower than 93° C (200° F); soluble in 86° B naphtha to at least 80%; when 20 g are heated in an open vessel at 163° C (325° F) for 5 hr, the loss in weight by volatilization shall not exceed 20%; it shall be soluble in carbon bisulphide to at least 99.5%.

An Approved Method of Preparing an Oil Emulsion which has been used to considerable extent by the City of Boston is to dissolve 25 to 30 lb of cottonseed soap in 100 gal of hot water; to this solution is added 200 gal of the emulsion oil and the mixture is then agitated for about 20 min. The mixing may be done in the tank of an ordinary watering cart and it is then drawn off into a large storage tank. This concentrated emulsion is then transported to the points where it is to be used and further diluted with water to the desired strength for application.

A Typical Specification for Emulsified Oil to be purchased from the manufacturer ready to be diluted with water for application is as follows: The compound must be of an asphaltic petroleum base, showing not less than 35% asphaltic residue, so compounded that it is easily miscible with water in varying proportions of 10 to 50%, and when so mixed with water, it is suitable for application to the road thru the ordinary sprinkling wagons. The emulsion when spread upon the road shall be entirely without odor. The emulsion shall have such drying and penetrating properties that when applied to a broken stone surface under direct sunlight, at a temperature of not less than 10° C (65° F) and 60% of humidity, it will not adhere to vehicle tires or soles of shoes after 5 hr from the time of its application. The compound shall possess the following characteristics: It shall be free of objectionable coal tar products and sulphurous hydrogen odors; specific gravity not lighter than 0.950; flash point not lower than 93° C (200° F); burning point not lower than 149° C (300° F); when heated in an open vessel for 5 hr at 110° C (230° F), the loss shall not exceed 20%; and at 140° C (284° F), the loss shall not exceed 25%. The compound must be entirely soluble in carbon disulphide. It shall not contain more than 1% inert mineral matter.

Application of Emulsions. These emulsified oils are diluted with about three parts of water to one part of oil for first applications, and for subsequent applications may be reduced to four parts water to one of oil if conditions warrant it. The emulsion is generally applied with the ordinary watering cart and a 600-gal cartload should cover an average of 3500 sq yd of roadway surface. The interval between the first and second applications should be from 5 to 7 days, and between the subsequent applications from 1 to 6 weeks, depending upon traffic and weather conditions. The cost of effective dust laying by the use of oil emulsions varies from 2 to 4 cents per sq yd for the usual watering season of 7 or 8 months.

Cost Data, District of Columbia. (12b). In 1910, 190 600 sq yd of broken stone roads were treated with oil emulsions. The following table gives cost and amount of work. On sections 1, 2, and 4, Standard emulsion was used at a cost of 4 cents per gal plus freight. On sections 3, 5, and 6, a product of the Indian Refining Co. was used at a cost of 6 cents per gal.

Section	Sq Yd Oiled	Total Gal	Cost of Labor, etc, Cents per Sq Yd	Cost of Material, Cents per Sq Yd	Number of Applications
1	32 800	8 000	0.553	1.055	6
2	9 800	2 345	0.533	1.041	6
3	72 200	21 545	0.462	1.653	9
4	40 800	10 988	0.669	1.166	12
5	13 500	3 730	0.400	1.651	9
6	15 500	3 450	0.358	1.335	6

7. Light Oils

Oils Used as Dust Palliatives comprise crude petroleums, distillates and fluid residual oils from the distillation of crude petroleum, and cut-back oils prepared by fluxing residuums with distillates. Crude oils are not used to a great extent for this purpose as they are not readily obtainable except in the vicinity of the oil fields where they are produced, and are generally refined to obtain, for other purposes, their more valuable constituents. The California and Mexican crude oils are, however, used to some extent. These oils are known as asphaltic oils and are preferable to the paraffin oils for highway work. Crude paraffin oils are seldom used for purposes of highway work on account of their greasy nature and lack of binding qualities, and also because their constituents are of much greater value for other purposes.

Non-Asphaltic Road Oils for dust laying purposes, several of which are on the market and sold under trade names, are used to some extent in cities and towns. These oils are generally distillates from either asphaltic or paraffin petroleums. They are very light, have no binding properties, and their effects are of short duration, necessitating frequent application. This class of oils has certain advantages over asphaltic oils in that they are cleaner, comparatively odorless and require no covering.

The following Table II by Hubbard (4), shows the differences in properties possessed by three kinds of crude petroleum.

Table II.—Results of Tests of Crude Petroleums

Kind of Oil	Specific Gravity	Flash Point	Volatility at 100° C (212° F) 7 hr	Volatility at 160° C (320° F) 7 hr	Volatility at 205° C (401° F) 7 hr	Residue
Pennsylvania, paraffin	0.801	a	47.3%	58.0%	68.0%	b32.0
Texas, semiasphaltic. .	0.904	43° C (109° F)	20.0%	27.0%	49.0%	c51.0
California, asphaltic. .	0.939	26° C (79° F)			d42.7%	e57.3

a. Ordinary temperature. b. Soft. c. Quick flow. d. Volatility at 200° C (392° F), 7 hr. e. Soft maltha, sticky.

As shown in the Table, the specific gravity increases from the paraffin to the asphaltic oil. This is also true for the percentage of residue, while the volatility decreases correspondingly.

A comparison of the residuums obtained from refining oils similar to those described in Table II is shown in Table III.

Table III.—Results of Tests of Petroleum Residuums

Kind of Oil from which Residuums came	Specific Gravity	Flash Point	Volatility at 200° C (392° F) 7 hr	Residue	Solid Paraffin	Fixed Carbon
Pennsylvania, paraffin	0.920	186° C (367° F)	14.2%	a85.8%	11.0%	3.0%
Texas, semiasphaltic. .	0.974	214° C (417° F)	6.2%	93.8%	1.7%	3.5%
California, asphaltic. .	1.006	191° C (376° F)	17.3%	82.7%	0.0%	6.0%

a. Soft.

In comparing these results, an increase in specific gravities in the same direction as in the case of the crude petroleums will be observed. The

volatility and percentage of residue, however, are not in the same order. As these depend wholly upon the point at which distillation is stopped in the process of refining, such a result is to be expected. In comparing the crude oils with the residuums it will be seen that the latter, as would naturally be supposed, carry a greater percentage of non-volatile constituents, and other things being equal, are therefore of more value as permanent binders.

Fluid Residual Oils obtained from the distillation of crude petroleum are used to a considerable extent in the United States as dust palliatives. Those best suited for the purpose are the residuums from the California, Mexican and some Texas petroleums. The density of these residuums varies considerably from that rich in paraffin hydrocarbons with a specific gravity of about 0.920 to that containing only asphaltic hydrocarbons with a specfic gravity of about 1.000, and the lighter residuums with a specific gravity not exceeding 0.950 are generally used for dust laying purposes.

Cut-Back Oils, which are oils prepared for use as dust palliatives and binders by fluxing heavy residual asphalts with volatile distillates, give very good results. By this method of preparation they can be made of the desired consistency for application and after application the light fluxing material quickly volatilizes, leaving the heavy asphaltic constituents evenly spread on the road surface. Cut-back oils may be obtained having varying specific gravities and asphaltic contents, but usually only the lighter grades are of this type, as these grades are not as readily obtainable in the form of residuals as the heavier grades, on account of the fact that, by the process of refining the crude petroleum to obtain the more valuable products, most of the light constituents are removed.

On broken stone and gravel road surfaces where the traffic is light, a residual or cut-back oil which meets the following specifications may be used with good results and will ordinarily maintain a dustless condition with from two to three applications a year.

Specific gravity at 15.6° C (60° F)	0.920 to 0.950,
Asphalt content at 100 penetration at 25° C (77° F) after evaporation at temperature not exceeding 260° C (500° F)	not less than 45%,
Loss in weight, by heating 20 g 5 hr at a temperature of 163° C (325° F)	not more than 25%,
Bitumen soluble in CS_2 at air temperature	not less than 99.5%,
Bitumen soluble in 76° B naphtha at air temperature	not less than 85%,
Flash point	not less than 54° C (130° F).

On broken stone and gravel road surfaces subjected to a considerable amount of traffic, a large percentage of which is of rubber-tired motor vehicles, excellent results are obtained in the work of laying the dust and of preserving the road surface by the use of oils meeting the following specifications.

Specific gravity at 15.6° C (60° F)	0.940 to 0.970,
Asphalt content at 100 penetration at 25° C (77° F) after evaporation at a temperature not exceeding 260° C (500° F)	not less than 60%,
Loss in weight by heating 20 g 5 hr at a temperature of 163° C (325° F)	not more than 20%,
Bitumen soluble in CS_2 at air temperature	not less than 99.5%,
Bitumen soluble in 76° B naphtha at air temperature	not less than 85%,
Flash point	not less than 54° C (130° F).

Application. Fluid road oils are usually shipped in tank cars of from 6 000 to 10 000 gal capacity. These tanks are generally equipped with steam coils for the purpose of heating the oils if they are of such consistency as to require it for application. In the application of oils having a specific gravity of less than 0.950 and an asphaltic content of 50% or less, heating is not generally required when the air temperature is above 21° C (70° F), but with oils heavier than as above described better results will be obtained by heating before application to about 66° C (150° F). By heating, the heavier oils can be more easily handled and more evenly spread in the desired quantities. Where possible it is advisable to have the tank car set at an elevation above the distributing vehicle so that the oil may be drawn off by gravity. Otherwise it is pumped out either by hand or power pump.

Non-asphaltic and very light asphaltic road oils which are used cold may be applied to the road surface by means of the ordinary water sprinkling cart or gravity distributors, but much better results are obtained by the use of some type of pressure sprayer, even for these light oils. In the application of the heavier grades of road oils, altho the gravity distributor may be used, it is advisable to use pressure sprayers whenever possible. Before applying oils to the road surface it is quite essential that the surface should be cleaned and all loose, fine dust removed, especially when the heavier grades are to be used. The heavier the oil used the more important it is that the surface should be thoroly cleaned. To obtain the best results the oils should be applied as soon as the surface has dried out after a heavy rain or after a thoro wetting with a watering cart, as the fine dust particles are thereby washed from the surfaces of the aggregate and better penetration and adhesion is obtained. At the time of application, however, the surface of the road should be dry and warm. In the treatment of gravel surfaced roads, the washing of the surface is particularly advisable. Before treatment with road oils the surfaces should be put in good repair and all holes and depressions patched and filled. Surface treatments of roads with asphaltic oils as dust palliatives will not provide a new surface for an old worn-out one, but will greatly aid in the preservation and maintenance of a good surface.

The Amount of Oil to be used for each treatment depends upon the condition of the road surface and the kind of oil used. In the use of the lighter oils on a broken stone road surface in good condition, from 1/8 to 1/10 of a gal per sq yd is sufficient, if applied with a pressure sprayer, to lay the dust for from 3 to 6 months. If the road is well worn down to the larger stones, from 1/4 to 1/8 gal per sq yd should be used, and a covering of sand applied. For gravel surfaced roads about the same quantities should be used for similar conditions. If it does not cause too great inconvenience to traffic, it is advisable to close the roadway for a few hours after the application of oil, to allow the oil to penetrate the surface as much as possible before covering with the sand or screenings. One cubic yard of sand or stone screenings will cover an average of 100 sq yd of oiled road surface.

Oiling Earth Roads, according to Piepmeier (26), "will not change their type, and it is folly to expect anything like a permanent road to result from the continued use of oil. Many have thought that after the road had been oiled for a number of years the surface would become saturated and no further oiling would be necessary. Tax payers should be warned against such expectation. The writer has examined a number of streets and roads that have been oiled annually for a period of 10 years and, while it takes a little less oil after the road has been oiled a few years, there is no indication

that such treatments may be eliminated if the desired results are to be expected. There are many earth roads that can be effectively maintained by the intelligent use of oil and the road drag. Besides being graded and drained, the surface should be smooth, free from dust and loose material, vegetation, sod or foreign material of any kind. It should then be rolled with a heavy roller or tractor, or opened to traffic until the entire surface that is to be oiled is uniformly compacted.

"The best time to oil an earth road is soon after a light rain and before the road is rutted. However, the surface should be sufficiently dry to prevent the wheels of the distributer from picking up mud. It is much better to oil on a wet surface than on one which is covered with dust. One of the best oiled roads was treated four times during the summer at the rate of ⅛ gal per sq yd per treatment. When too much oil is applied in one application, it is not only wasted but is often very disagreeable to traffic. When applied in small quantities at different seasons, the oil retains its life, keeps down the dust better, and makes a more waterproof surface. The roads should be sanded after either hot or cold oil has been applied. Clean, hard sand is much better on a road surface than dust or road sweepings. Sand may be applied at a rate of 1 cu yd to each 150 sq yds of road surface. The sand gives an oiled surface more stability. It retains the oil, assists in preventing wear and aids in keeping down the dust. A light application of sand is a justifiable expense on a majority of oiled earth roads.

"A light greasy paraffin oil will lay the dust for a short period but evaporates readily and aids very little in preserving the surface. The light oils that have a natural asphaltic base or a semiasphaltic residue have more lasting qualities, as they more completely fill the pores of the earth surface and readily shed the water and prevent the formation of dust. The best grade of natural asphaltic oils for earth roads will vary from 50 to 65% in asphaltic content, and may ordinarily be applied cold. Some cleaning is generally necessary prior to the first application of oil and this will cost from $25 to $50 per mile. Road oil can be purchased for 3 to 7 cents per gal, depending upon the quality. With average conditions and with a medium priced oil, the average cost of oiling alone per application may be from $200 to $250 per mile of road 15 ft wide."

The Cost of the treatment of road surfaces with oils, varies with the quality and quantity of the oil used and with the varying cost of transportation. Road oils such as are used as dust palliatives, delivered in tank cars thruout the United States, will cost from 3½ to 4½ cents per gal. The cost per sq yd for each treatment for the lighter oils will vary from 1½ to 2½ cents.

Philadelphia Practice. Connell (11b) states that the material generally used consists of asphaltic road oil from 18° to 23° B gravity. "This material is applied to all of the macadam roads that are not in fit condition for the first-class bituminous surface treatment and to all earth roads, and is applied at the rate of 0.2 to 0.25 gal per sq yd. On some roads, depending upon the amount of traffic and whether or not the road is shaded, it is necessary to treat the road in May and treat it again in September. Such roads, however, are the exceptions. In most cases this method of treatment will last for one season. The roads as a rule are not swept before the application, nor is any covering put over this bituminous material, as it is applied in such small quantities that there is scarcely any necessity for covering. The purpose in putting on this small quantity is to insure its disappearing from the road before the winter sets in, in order to avoid the mushy condition that prevails when there is too much oil on the road in this season of the year." Details of cost of using asphaltic road oil, 21° to 23° B, in dust laying in 1915 follow: Square yards treated, 1 167 790; amount per sq yd, 0.23 gal; cost per application, including material per sq yd, 1.1 cents."

Methods and Cost of Oiling in Kansas City, Mo. (27). "Approximately 50 miles of macadam roadways are oiled twice a year by the Park Board of Kansas City. The oil used is a residuum of Kansas oils, which has an average specific gravity of 93 at 15.6° C (60° F). The conditions for oiling are as follows: (1) Before oiling, such repair work as is necessary should be done on the roadway, as the oil forms a cushion over the patch and protects it from raveling; (2) the road surface should be hard and clean and all loose material removed; (3) the road surface should be dry; (4)

only one-half of the roadway should be oiled at a time, if for no other reason than a protection and courtesy to the public; (5) the weather should be warm, with no prospects of rain, as rain on a freshly oiled surface will wash away much of the oil, sometimes completely ruining the job.

The oil is distributed by steel tank wagons, of about 600 gal capacity. To the back of each wagon is attached a sheet iron trough into which the oil is discharged by three 2-in valves, flowing evenly upon the roadway thru small holes in the bottom of the trough. The oil is distributed lightly from the tank wagon upon the roadway, and the tank is immediately followed by the rotary street broom, which spreads the oil over the surface in a thin even coat. Two to four men with hand brooms are necessary to keep oil from running into gutters, and to spread oil on uneven places in the roadway, and at intersections with streets. The oiled surface is then covered with a thin coat of limestone dust, the finest product of the crusher. This is spread from the rear of an ordinary wagon by two men working from the ground with No. 2 scoop shovels.

Detailed Cost of One Application of Oil on Benton Boulevard, Kansas City, Mo.

	55 010 Sq Yd	
	Hr	Per Sq Yd
Foreman, at $2.50 per day	19½	$0.00026
Man, hr on brooms, at $0.25	58½	0.00011
Man, hr spreading dust, at $0.25	89½	0.00040
Man, hr oil wagons, at $0.25	19½	0.00009
Man, hr extra water, etc, at $0.25	28½	0.00011
Team, hr on dust, at $0.50	77	0.00070
Team, hr on broom, at $0.50	21½	0.00019
Team, hr oil wagons, at $0.50	31	0.00029
Cost of delays	......	0.00005
Oil, at $0.025 per gal	3590*	0.00163
Dust, at $0.30 per cu yd	54†	0.00029
		$0.00412"

*Gal †Cu Yd

8. Light Tars

Certain light tars are suitable for use as dust palliatives, under the same general conditions and on the same types of road surfaces as asphaltic oils. These tars are obtained from coal and petroleum in the manufacture of illuminating gas and coke by the process of destructive distillation. They are of two kinds, generally known as coal tars and water-gas tars. The coal tars include gas-house tars and coke-oven tars. Various forms of tars are used in road work, such as crude tars, dehydrated tars, refined tars, cut-back tars and various mixtures of any of these. Only such as may be applied to the road cold are generally considered as dust palliatives, altho some of the lighter forms of those which require heating for application accomplish the same purpose of rendering the road surface dustless, with the added benefits of road preservation. Altho the first cost of the heavier material is slightly more, on account of its greater durability it is often fully as economical in the end and sometimes more so. The advisability of using either the cold application or the hot application materials depends, as with other materials, upon the condition of the surface and the kind and amount of traffic. Generally the heavier grades of tars are unsuited for treatment of gravel surfaced or earth roads, unless

the gravel is particularly clean and free from clay and fine dusty material. They are best suited to the treatment of broken stone road surfaces.

Crude Tars generally give the least satisfactory, and in some cases unsatisfactory results, on account of the presence of water and disagreeable odors, and lack of uniform quality. Dehydrated tars, from which all water, ammonia compounds and some of the light oils have been removed, are sometimes used as dust palliatives with satisfactory results. This form of tar may be obtained of such consistency that it may be used for cold applications. Refined tars are generally considered best for all classes of highway work including dust laying, but most of the refined tars are of such consistency as to require heating for application to the road, and therefore are not considered as dust palliatives. However, as stated before, when used for road treatments, they serve this purpose as well as that of a road binder, for which they are used extensively. Tars which have been refined to the consistency of pitch are sometimes cut back with tar distillates to the desired consistency for dust palliatives. This form of tar, if prepared especially for highway work with proper cut-back material, sometimes gives good results, altho it is not recommended by all authorities. The blending of various tars often produces a grade of tar which is much better for highway work than any one alone. By this method the proportion of the most desirable constituents may be increased and that of the least desirable, decreased so that the resulting product gives excellent results. Some of the commercial products which are on the market are of this form, and are used to a considerable extent.

Specifications for Light Tars. Tars which meet the following specifications are suitable for use as dust palliatives, for cold application:

Specific gravity at 25° C (77° F)	1.05 to 1.18,
Free carbon	2 to 15%,
Viscosity, Engler, 100 cu cm at 60° C (140° F)	not over 125 sec,
Distillation by weight,	
Up to 170° C	not over 5%,
Up to 235° C	not over 18%,
Up to 270° C	not over 30%,
Up to 300° C	not over 40%.

The lighter form of tars which may be used as dust palliatives by the hot application method should meet the following specifications:

Specific gravity at 25° C (77° F)	not less than 1.19,
Free carbon	10 to 25%,
Float test at 100° C (212° F)	18 to 30 sec,
Distillation by weight,	
Up to 170° C	not over 1%,
Up to 235° C	not over 10%,
Up to 270° C	not over 16%,
Up to 300° C	not over 20%.

The Application of Tars to road surfaces as dust palliatives should be by pressure sprayers, as this method is the most effective and economical. In the use of tars it is most essential that the surface shall be thoroly cleaned of all loose or matted dust or dirt. Sweeping is not always effective in removing all dust particles and, as in the use of asphaltic oils, the road surface is in the best condition for the application of tar soon after a heavy rain. It must, however, be dry and warm at the time of application. Whenever tars are used they must be covered with sand or stone screenings before traffic is allowed to go upon them. A period of from 5 to 10 hr should elapse after the application of the material on first treatments before it is covered. On subsequent treatments it may be covered imme-

diately after application. With the cold application of the lighter material from ⅛ to ¼ gal per sq yd is used and one treatment is usually effective for about 1 year.

Cost. The cost of treatments with tars depends upon the grades of tar used and the proximity of the work to the plant where it is produced. Within a distance of from 10 to 15 miles of large cities, where gas plants are usually located, it can be obtained delivered in tank wagons, either horse-drawn or motor-driven, from which it can be directly applied to the road surface. The cost of the light tars at the plant is about 5½ cents per gal. The cost of delivery within a radius of 10 miles of the plant varies from ½ to 1 cent per gal and the cost of application by pressure sprayer is about ½ cent. If it is necessary to ship by tank cars the cost is increased by the freight charges and the expense of handling from the cars to the distributing wagon. The cost of covering with sand or stone screenings varies from 1 to 2 cents per sq yd.

9. Miscellaneous Materials

Patented Compounds made from waste by-products from various industries are used to some extent as dust palliatives. Vegetable oils, animal oils and fats, sulphite liquors and molasses residues have been used in these compounds and have given varying results as temporary dust layers only.

Vegetable Oils, Animal Oils and Fats contain no binding properties, and if used alone act in the same manner as water, merely laying the dust by wetting the particles, but being less volatile than water have a more lasting effect. They are usually combined with an alkali to form a soap to be used for emulsifying mineral oils to form concentrated emulsions. These products are sold under trade names in various sections of the world.

Waste Sulphite Liquor, which is produced from the manufacture of wood pulp by the sulphite process, is a by-product of no value and has been allowed to run to waste in nearby streams. In the crude state it has little binding value, but in concentrated form it exhibits this characteristic to a considerable extent. It is soluble in water and therefore its effects as a binder in road work are rapidly diminished by rains. The addition of small percentages of semiasphaltic oil tends to increase its lasting effect by making it waterproof. Patented preparations of waste sulphite liquor are on the market for use as dust layers and road binders. One of these, sold under the trade name of GLUTRIN, has been used to a considerable extent. It is claimed for this material that it contains the weak acids that are in the sap of the tree and which are capable of dissolving silica or stone; when it is placed on the roadway and comes in contact with the stones, these acids attack that portion of the stones composed of silica, dissolves it and forms, when it becomes dry, a bond which is insoluble in water and proof against changes in temperature. Particularly good results are claimed for this material on roads built of limestone, clayey gravel or red shale. In the use of Glutrin as a dust layer it is applied to the road surface with the ordinary watering carts. It is purchased in concentrated form and is mixed in the proportion of from 25 to 50 gal of the material to about 500 gal of water. It is then sprinkled on the road in such quantities as for ordinary dust laying with water. The treatment is repeated after a few weeks and the interval between each subsequent treatment should increase considerably, as after

two or three applications the road becomes impregnated with the material and a bond is formed which produces a hard surface which will be dustless for a considerable period. The number of treatments required for a season depends to a large extent on traffic conditions. This material in concentrated form costs from 12 to 15 cents per gal f. o. b. destination.

Molasses Residues, which are by-products from the manufacture of sugar, have been used to a limited extent as a dust palliative in localities near the sugar refineries, generally for experimental purposes. Being soluble in water, they are of little value unless waterproofed. Experiments have been made with a mixture of molasses, lime and oil. This molasses residue is of some value for other purposes and it is little used in road work.

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SECTION 14

BITUMINOUS SURFACES

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GENERAL DATA

1. Classification

General Description. Bituminous surfaces are used on earth, broken stone and gravel roads, on bituminous and cement-concrete pavements, and to a certain extent on brick and wood block pavements. In this section there will be considered primarily methods of constructing and maintaining bituminous surfaces on broken stone and gravel roads, while bituminous surfaces on earth roads, bituminous macadam pavements, bituminous concrete pavements, asphalt block pavements, cement-concrete pavements, brick and wood block pavements will be treated in the sections devoted to the several types of roadway surfacings.

Distinction Between Treatments with Palliatives, and Bituminous Surfaces. As oils and tars are used in the construction of bituminous surfaces and are likewise referred to in Sect. 13 covering dust prevention by the use of palliatives, the distinction between treatments with palliatives and the construction of bituminous surfaces should be noted. Palliatives are materials which mitigate or abate the dust nuisance, while bituminous surfaces consist of superficial coats of bituminous materials with or without the addition of stone or slag chips, gravel, sand or materials of a similar character. It is evident, therefore, that the reapplication of oils and tars when used as palliatives may result in the formation of bituminous surfaces. Hence, the line of distinction between treatments with palliatives and the construction of bituminous surfaces is not clearly defined. The methods

of construction usually considered under the heading of bituminous surfaces are confined to those methods which ordinarily result in a bituminous surface, efficacious for 6 months to 2 years.

Classification of Bituminous Surfaces. Bituminous surfaces may be considered as divided into two classes. The first class consists of thin superficial coats of bituminous material with or without the addition of such materials as stone chips, fine gravel or sand. When this type of bituminous surface has been under traffic for from 1 to 2 years, the road metal, or other material composing the wearing course, is exposed. The second class consists of coats of bituminous material of appreciable thickness, usually over ½ in, and are formed by the application of one or more treatments of bituminous material with sand, gravel or stone chips added. Surfaces of this class are known as bituminous carpets or blankets. They rarely wear down uniformly to the wearing course and hence usually increase unevenly in thickness by retreatments.

2. Historical Development

Development in Europe. As early as 1871, Francou of Auch, France, actually employed tar as a surface treatment in a few trials. His method was to spread the unheated tar on the surface and then set fire to it in order to harden the surface. Christophle in 1880 used tar on a road at Saint Foy, and in 1888 another experiment was tried with this material at Saint Gaudens by Lavique. In 1896, Girardeau conceived the idea of applying hot tar to a road surface by observing the better results obtained when a cold tar application was acted upon by the heat of the sun. It was not until 1901, however, that systematic experiments were carried out. Such experiments were started by Dr. Guglielminetti at Monte Carlo, Geneva and Nice, using coal tar and brushing the same into the road surface. In 1902 trials were carried out at Champigny by the engineers of the Department of Roads and Bridges of France. In the 1903 report on these trials, the French engineers formulated all of the basic principles of superficial tarring.

Development in the United States. Dust suppression was the main cause of the rapid development of the method of surface treatment. While in Europe it led to superficial tarring, in the United States, the first trials of this method were made with light oils. Oil was used for this purpose in 1894 at Santa Barbara, California. Further trials were made in 1898 and oils were used to a very slight extent in different parts of the country up to 1905. A few similar trials were made in Europe with indifferent success. After 1905 the use of oils as a dust palliative rapidly increased in the United States. As a general rule they were light in character and could be applied cold. Tar was first used for a surface treatment in 1894 in Montclair, N. J. It was not until 1905, however, that tar surface treatments were used again. After 1906, the use of both oil and tar surface treatments increased at a rapid rate.

3. Characteristics

General Considerations. A properly constructed bituminous surface on a broken stone or gravel road is impervious and is easily cleaned. It increases the durability of the road, yields no dust due to abrasion of the roadway surface, and enables the crown to be reduced. The lowering of tractive resistance and the character of foothold will depend upon the kind

and amount of the bituminous material used and the grade of the road. When asphaltic materials are used the noise caused by horse-drawn vehicles is comparable to that characteristic of wood block pavements subjected to the same kind of traffic, while bituminous surfaces constructed with a thin coat of tar give forth more noise; in some cases, comparable to that emanating from the impact of horse-drawn vehicle traffic on sheet-asphalt pavements. It is self-evident that the various types of bituminous surfaces are adaptable to many conditions, hence complete preliminary investigations are requisite before the kind of material and the details of the method of construction are adopted. Bituminous carpets and thin bituminous surfaces are particularly adaptable to passenger motor vehicle traffic, and hence usually will give the maximum return on the investment when the roadway is subjected to this class of traffic.

Limitations of Use of Bituminous Carpets. Dean (27) states that "It has been demonstrated that a tar carpet will carry economically 100 automobiles per day per ft in width of roadway, together with a horse-drawn traffic of 15 vehicles per day per ft in width of roadway. A tar blanket is not suitable and should never be used to sustain heavy horse-drawn traffic, but is suitable and economical in carrying automobile traffic. Failures that have occurred with a heavy asphaltic oil carpet have occurred where the ratio of the number of automobiles to the number of horse-drawn vehicles was not any greater than two to one, and if the horse-drawn vehicles are of the heavy two-horse type, with narrow tires, no amount of automobile traffic appears to be sufficient to counterbalance the destructive effect of 15 heavy horse-drawn vehicles per ft in width per day."

Canadian Experience with Oil Carpets, according to McLean (41), is as follows: "An early tendency in the use of asphaltic oils for dust prevention was to seek a carpet coat of ⅛ to ½ in in thickness, made up of successive layers of oil and stone chips or gravel. It was believed that a heavy bituminous covering might thus be cheaply built up. This process has been found impracticable, however, as a thick covering has a tendency to pit or to roll, forming a wavy, uneven road surface. Practice now tends to the use of such a grade of asphaltic oil as will produce a thin, tough film of asphaltic coating rather than the thicker coat of bitumen and gravel."

Slipperiness of Tar Surfaces. Some objection has been raised in England to superficially tar-coated roads, due to alleged slipperiness. Without doubt much slipperiness is due to a smooth coat of tar, the ideal mosaic surface of tar and stones not being secured. Heavy traffic and late tarring contribute to greasiness of a road with consequent slipperiness, since tar applied late in the year and subjected to heavy traffic works up into an emulsion more readily than tar which was applied at the beginning of the season and has set hard by winter.

A British Report (55) on this subject is as follows: "It appears to be generally agreed that any impervious surface must be somewhat slippery and greasy at times of hoar frost, light rains and general humidity. The general practice is to cleanse the surface as frequently as necessary by either washing or brushing, and to sprinkle sharp sand, fine granite chippings, or other similar material sparingly over it. In many cases where surface tarring is adopted on country roads it is the practice to avoid tarring steep hills."

Effect of Use of Bituminous Materials on Public Health, Fish Life and Vegetation. There is no danger of pollution of fish streams if proper precautions are taken during the treatment of a road and if refined tar is employed. It has been shown that if crude tars, having considerable ammoniacal liquor, are used in a manner which will permit of portions of the tar being washed into the stream, it will result in killing certain kinds of fish, trout being especially susceptible. The opinion has been expressed by many that superficial tarring does not injure vegetation except from the possible prevention of the percolation of water thru the road surface

to the roots of trees. Altho certain horticulturists in France have claimed that tarred dust injures vegetation, proof of this assertion has not been presented.

Report of British Engineers (55) to 3rd Int. Road Cong.: "Hygienically tars and bituminous compounds have the advantage of producing *per se* very little dust or mud, but on the other hand the non-absorbent surface which they afford leaves the organic dust resulting from horse-droppings, vegetable débris, etc, free play in cases where such matter is not frequently flushed off the road surface. Tar has disinfecting and germicidal properties which are hygienically in its favor as a surfacing for roads. Conclusive evidence of any injury to vegetation from roads surfaced with either coal tar, pitch, or asphalte appears wanting. The surface washings from roads surfaced with coal tar may be polluted to an extent which will render them injurious to fish life unless the washings are sufficiently diluted with other water. The injurious character of the pollution is affected by the quality of tar used: The most injurious constituents of the tar being, in order, ammonia and its compounds, light oils, and phenols. Hence tar for use on roads in the neighborhood of fishing waters is required to be as nearly free as is practicable from these bodies. Surface washings from roads coated with a properly prepared or refined coal tar are believed to be absolutely harmless to fish life if diluted with 20 times their volume of other water of unobjectionable quality."

Conclusion Adopted by 3rd Int. Road Cong. "Sufficient information is now available to enable engineers to select and specify bituminous binders which will have no prejudicial effect upon public health, fish life, or vegetation; but which, on the contrary, will conduce to conditions of considerable hygienic advantage."

BITUMINOUS MATERIALS

4. Bituminous Materials

The different kinds of bituminous materials used are asphaltic oils, cut-back asphalts, crude and refined water-gas tars, crude and refined coal-gas tars, combinations of refined tars, and combinations of refined tars and asphalts. There has been noted a growing objection to the use of materials, for the construction of bituminous surfaces, which require from 2 to 6 weeks to set up to such an extent that tracking will not occur. Materials, which have given satisfactory results from this standpoint, are refined coal tars and water-gas tars, cut-back asphalts, and combinations of asphaltic materials and refined tars. Within 24 to 48 hr, thin bituminous surfaces constructed with the foregoing materials, using from ¼ to ½ gal per sq yd and a thin covering of stone chips, have set up so that no tracking is noticeable. For the construction of carpets on broken stone and gravel roads, both asphaltic oils and tars are used.

Report of Advisory Board on Highways, N. Y. State Dept. of Efficiency and Economy (19), on use of fluid petroleum products for surface treatments. "The reasons for condemning these specifications (N. Y. Highway Comm. 1913 specifications for cold oil and hot oil) are based upon knowledge of materials having similar physical and chemical properties and the use of such materials in the manner specified. These reasons are as follows: (1) Oils which meet these specifications require considerable time in which to set up, when used in the manner specified; (2) all petroleum products, while in a fluid state, act to a certain extent as lubricants, when used as specified; (3) it is therefore evident that more or less movement of the road surface will take place under traffic during the setting-up period; (4) the bituminous mats or carpets formed invariably become wavy and full of humps and ruts under heavy traffic; (5) due to the character of the resulting surface further maintenance is rendered difficult and costly; (6) prior to retreatment of roads thus repaired, it is often necessary to remove considerable portions of the bituminous mats with picks and shovels or with scarifiers. The above conclusions are in accordance with the results of our investigations of many miles of highways treated as described under substantially the same specifications."

Sharples 16c) states that "The heavy tars and asphaltic oils are suitable, as surface applications, when the traffic is mainly automobiles, and give excellent results. Such,

at least, has been the experience on the main state highways in New England. When, however, to the automobile traffic is added a considerable amount of steel-tire traffic, the conditions change; and if, as is the case in the centers of towns and in the suburban districts of cities, the steel-tire traffic predominates, heavy bituminous surfaces are often failures. During the first rainy period, the steel-tire traffic and the horses' calks will probably cut up the surface, let the water into it, emulsify the bitumen, and produce a very disagreeable bituminous mud. For such traffic conditions, the thinnest possible treatments will give the best results. This is true of both tars and oils. In choosing the bituminous material for a surface which will have to be renewed often, care must be taken to select a material which will allow the application of repeated layers. On a number of roads the material gave good results on the first treatment, but further treatments added from year to year have produced a rolling and easily moved surface, due to the formation of a thick, plastic blanket."

Sources, Manufacture, Physical and Chemical Properties, Tests, Transportation, Storage and Inspection of Bituminous Materials. See Sect. 12.

5. Specifications for Bituminous Materials

Forms of Specifications for bituminous materials, as follows, were adopted at the first conference of State Highway Testing Engineers and Chemists, held at the U. S. O. P. R. in Feb., 1917, (57b).

" **Specification for Tars for Cold Application.**

" GENERAL. The tar shall be homogeneous.

" PHYSICAL AND CHEMICAL PROPERTIES. It shall meet the following requirements:

1. Specific gravity 25°/25° C (77°/77° F) .... to ....
2. Specific viscosity at *......° C (....° F) .... to ....
3. Total distillate by weight:
   to 170° C (338° F) .... not more than ......%,
   to 235° C (455° F) .... not more than ......%,
   to 270° C (518° F) .... not more than ......%,
   to 300° C (572° F) .... not more than ......%.
   Melting point of residue ......° C (......° F) to ......° C (......° F).
4. Total bitumen, soluble in carbon disulphide, ...% to ......%.

" METHODS OF TESTING. Tests of the physical and chemical properties of the tar shall be made in accordance with the methods described, or referred to, on page ...... of these specifications, Tests Nos. ....

" NOTES. 1. In some instances it may be desirable to insert a specific gravity of distillate requirement after the melting point requirement, in which case the wording should be: Specific gravity of total distillate 25°/25° C (77°/77° F) .... to ....

2. In some instances it may be considered desirable to insert a requirement for solubility in dimethyl sulphate of one or more fractions of the distillate. In such cases insert as follows: Solubility in dimethyl sulphate of distillate from ....° C (....° F) to ....° C (....° F) ......% to ......%."

" **Specification for Refined Tars for Hot Application.**

" GENERAL. The refined tar shall be homogeneous and free from water.

" PHYSICAL AND CHEMICAL PROPERTIES. It shall meet the following requirements:

1. Specific gravity 25°/25° C (77°/77° F) .... to ....
2. Float test at †....° C (....° F) .... sec to........sec.
3. Total distillate by weight:
   to 170° C (338° F) .... not more than ......%,
   to 235° C (455° F) .... not more than ......%,
   to 270° C (518° F) .... not more than ......%,
   to 300° C (572° F) .... not more than ......%.
   Melting point of residue ....° C (....° F) to ....° C (....° F).
4. Total bitumen, soluble in carbon disulphide, ...% to ......%.

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*It is recommended that the viscosity determination be made at 25° C (77° F) or 40° C (104° F), according to the nature of the product desired.

†It is recommended that the float test be made at 32° C (90° F) or 50° C (122° F), according to the nature of the product desired.

"METHODS OF TESTING. (Same as under Specification for Tars for Cold Application.)

"NOTES. (Same as under Specification for Tars for Cold Application, with the following addition.)

In some instances it may be desirable to specify the specific viscosity of the material at the temperature applied. In such cases insert as follows: Specific viscosity ....° C (....° F) .... to ...."

"Specification for Road Oils for Cold Application.

"GENERAL. The road oil shall be homogeneous and free from water.

"PHYSICAL AND CHEMICAL PROPERTIES. It shall meet the following requirements:

1. Specific gravity 25°/25° C (77°/77° F) .... to ....
2. Flash point .... not less than ....° C (....° F), or *....° C (....° F) to ....° C (....° F).
3. Specific viscosity at ....†° C (....° F) .... to ....
4. Loss at 163° C (325° F), 5 hr, ... not over......%, or *..... to .....%.
   ‡ Float test of residue at 50° C (122° F) .... sec to .... sec.
5. Total bitumen, soluble in carbon disulphide, not less than ......%.
6. Percent of total bitumen insoluble in 86° B naphtha ......% to ......%.

"METHODS OF TESTING. Tests of the physical and chemical properties of the road oil shall be made in accordance with the methods described, or referred to, on page ...... of these specifications, Tests Nos. ....

"NOTES. 1. In some instances it may be considered desirable to include a requirement for loss at 105° C (221° F), in which case the wording should be: Loss at 105° C (221° F), 5 hr, ... not less than ......%.

2. In some instances it may be considered desirable to include a requirement for the percentage of residue of .... penetration, in which case the wording should be: Percentage of residue of .... penetration ......% to ......%.

3. In certain cases the inclusion of all the tests listed or noted may not be desirable, but it is necessary to use certain combinations of the tests in order to secure a material suitable for a specified purpose."

"Specification for Road Oils for Hot Application.

"GENERAL. The road oil shall be homogeneous, free from water, and shall not foam when heated to ....° C (....° F).

"PHYSICAL AND CHEMICAL PROPERTIES. It shall meet the following requirements:

1. Specific gravity 25°/25° C (77°/77° F) .... to ....
2. Flash point .... not less ....° C (....° F) *or .....° C (....° F) to ....° C (....° F).
3. Specific viscosity at 100° C (212° F) .... to ....
4. Float test at ....††° C (....° F) ...... sec to ...... sec.
5. Loss at 163° C (325° F), 5 hr, ... not over ......% *or ....% to ......%.
   Float test of residue at 50° C (122° F) ...... sec to ...... sec (or penetration of residue at 25° C (77° F), 100 g, 5 sec, ... to ....).
6. Total bitumen, soluble in carbon disulphide, not less than ...... %.
7. Percent of total bitumen insoluble in 86° B naphtha ......% to ......%.

"METHODS OF TESTING. (Same as under Specification for Road Oils for Cold Application.)

"NOTES. (Same as Notes 2 and 3 under Specification for Road Oils for Cold Application.)

Specifications. The following specifications are given as guides and illustrations of practice in America and Great Britain. Satisfactory specifications covering bituminous materials for surface treatments must be

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*In cases where the presence of a volatile or light flux is desired, the second form of the flash point requirement and of the loss at 163° C requirement should be used; in all other cases the first form of requirement is applicable.

†It is recommended that the viscosity determination be made at 25° C (77° F) or 40° C (104° F), according to the nature of the product desired.

‡In case the oil is to be used as a dust layer only, this requirement is to be omitted.

††It is recommended that the float test be made at 32° C (90° F) or 50° C (122° F), according to the nature of the product desired.

based upon such local factors, as method of use, type and condition of roadway surface, climatic conditions, etc, and upon sources of supply and methods of manufacture of the bituminous materials. In order to obtain suitable bituminous materials at the lowest possible cost, it is necessary in some cases, to modify specifications from year to year. Again, developments in the art and science of the testing and use of bituminous materials often call for changes in specifications.

U. S. O. P. R. 1918. Specifications for Tar for Cold Application. "GENERAL. The tar shall be homogeneous.

"PHYSICAL AND CHEMICAL PROPERTIES. It shall meet the following requirements:

1. Specific gravity 25°/25° C (77°/77° F)..................1.100 to 1.140.
2. Specific viscosity at 40° C (104° F)..........................25 to 35.
3. Total distillate by weight:
   - To 170° C (338° F)........................not more than 2.0%,
   - To 270° C (518° F)........................not more than 25.0%,
   - To 300° C (572° F)....................... ......not more than 35.0%.
4. Total bitumen, soluble in carbon bisulphide...............95% to 100%.

"PURPOSE AND USE. This specification provides primarily for a material to be used in the surface treatment of macadam, gravel or shell roads, to form a thin wearing mat or carpet which may be built up by subsequent maintenance treatments of either the same type of material or a heavier product. It may also be used for maintenance of tar macadam or tar concrete pavements. The specification is intended to cover water-gas tar and low carbon coke-oven tar products."

Specifications for Tars to be Applied Cold on Broken Stone and Gravel Roadways, recommended in 1914 by Advisory Board on Highways, N. Y. State Dept. of Efficiency and Economy (19).

"TAR 'A' OPTIONAL WITH TAR 'B.'

1. Tar 'A' (water-gas tar) shall be homogeneous, and free from water.

2. Its specific gravity at a temperature of 25° C (77° F) shall be not less than 1.050 nor more than 1.140.

3. When tested by means of the Engler viscosimeter at 40° C (104° F) the specific viscosity of the first 50 cc passing the orifice of the viscosimeter, shall be not less than 12 nor more than 20.

4. Its bitumen, as determined by its solubility in chemically pure carbon disulphide at room temperature, shall be not less than 97.0%, and it shall show not more than 0.2% ash upon ignition of the material insoluble in carbon disulphide.

5. When distilled according to the tentative method recommended by Com. D-4, Am. Soc. Test. Mat., in 1911, not more than 1.0% shall distill below 170° C (338° F) and not more than 40.0% shall distill below 300° C (572° F).

"TAR 'B' OPTIONAL WITH TAR 'A.'

1. Tar 'B' (coal tar base) shall be homogeneous, and contain not over 2.0% of water.

2. Its specific gravity at a temperature of 25° C (77° F) shall be not less than 1.140 nor more than 1.180.

3. When tested by means of the Engler viscosimeter at 40° C (104° F) the specific viscosity of the first 50 cc passing the orifice of the viscosimeter, shall be not less than 8 nor more than 13.

4. Its bitumen, as determined by its solubility (upon a water-free basis) in chemically pure carbon disulphide at room temperature, shall be not less than 92.0% nor more than 97.0%, and it shall show not more than 0.2% ash upon ignition of the material insoluble in carbon disulphide.

5. When distilled according to the tentative method recommended by Com. D-4, Am. Soc. Test. Mat., in 1911, not more than 5.0% of oil shall distill below 170° C (338° F) and not more than 40.0% shall distill below 300° C (572° F)."

1917 Specifications for Refined Tars for Hot Surface Treatments, Am. Soc. Mun. Imp.

"PREVIOUS SERVICE. The Contractor will be required to show to the satisfaction of the Engineer, that the Company manufacturing the refined tar he proposes to use under a given specification has, for a period of at least 2 years, manufactured refined tar in a thoroly equipped plant; and that refined tar manufactured of bituminous

"METHODS OF
Application.)

"NOTES. (Same a
following addition.)

In some instances
material at the temp
cosity .° C (.. .° F

"Specification for Ro

"GENERAL. The roa

"PHYSICAL AND CHEM

1. Specific gravity 25°
2. Flash point ....
to ....° C (.. ° F).
3. Specific viscosity at
4. Loss at 163° C (325° F
‡ Float test of resi
5. Total bitumen, soluble
6. Percent of total bitum

"METHODS OF TESTING.
oil shall be made in accorda
. . . . . of these specifications,

"NOTES. 1. In some insta
ment for loss at 105° C (221° F
(221° F), 5 hr, ... not

2. In some instances it may
the percentage of residue of
be. Percentage of residue of ..

3. In certain cases the inclusio
but it is necessary to use certain
suitable for a specified purpose."

"Specification for Road Oils for

"GENERAL. The road oil sha
foam when heated to ....° C (.

"PHYSICAL AND CHEMICAL PRO

1. Specific gravity 25°/25° C (77
2. Flash point .... not l
.. ° C (.° F).
3. Specific viscosity at 100° C (21
4. Float test at .. ††° C (... °
5. Loss at 163° C (325° F), 5 hr
..... %.
Float test of residue at 50° C
of residue at 25° C (77° F), 100
6. Total bitumen, soluble in carbon
7. Percent of total bitumen insolub

"METHODS OF TESTING. (Same a
Application.)

"NOTES. (Same as Notes 2 and
Application.)

Specifications. The following

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material obtained from a similar source to that which he proposes to use shall have been in continuous and successful use in the surface treatment of broken stone roads for a period of at least 2 years previous to the date of the letting in which his proposal was submitted.

"REFINED TAR 'A' OPTIONAL WITH REFINED TAR 'B.'

1. Refined tar 'A' (water-gas tar) shall be homogeneous, free from water and shall not foam when heated to 121° C (250° F).

2. Its specific gravity at a temperature of 25° C (77° F) shall be not less than 1.140 nor more than 1.180.

3. When tested by means of the New York Testing Laboratory Float Apparatus, the float shall not sink in water maintained at 50° C (122° F) in less than 50 sec nor more than 110 sec.

4. Its bitumen, as determined by its solubility in chemically pure carbon disulphide at room temperature, shall be not less than 95.0% and it shall show not more than 0.2% ash upon ignition of the material insoluble in carbon disulphide.

5. When distilled according to the tentative method recommended by Com. D-4, Am. Soc. Test. Mat., in 1911, it shall yield no distillate at a temperature lower than 170° C (338° F); not more than 20.0% shall distill below 270° C (518° F), and not more than 30.0% shall distill below 300° C (572° F).

6. The melting point as determined in water by the cube method, of the pitch residue remaining after distillation to 300° C (572° F) in accordance with the test described in Clause 5 shall be not more than 75° C (167° F).

"REFINED TAR 'B' OPTIONAL WITH REFINED TAR 'A.'

1. Refined tar 'B' (coal tar base) shall be homogeneous, free from water, and shall not foam when heated to 121° C (250° F).

2. Its specific gravity at a temperature of 25° C (77° F) shall be not less than 1.170 nor more than 1.220.

3. When tested by means of the New York Testing Laboratory Float Apparatus, the float shall not sink in water maintained at 50° C (122° F) in less than 40 sec nor more than 100 sec.

4. Its bitumen, as determined by its solubility in chemically pure carbon disulphide at room temperature, shall be not less than 85.0% nor more than 95%, and it shall show not more than 0.2% ash upon ignition of the material insoluble in carbon disulphide.

5. When distilled according to the tentative method recommended by Com. D-4, Am. Soc. Test. Mat., in 1911, it shall yield no distillate at a temperature lower than 170° C (338° F); not more than 20.0% shall distill below 270° C (518° F), and not more than 25.0% shall distill below 300° C (572° F).

6. The melting point as determined in water by the cube method, of the pitch residue remaining after distillation to 300° C (582° F) in accordance with the test described in Clause 5 shall be not more than 75° C (167° F)."

British Standard Specification for No. 1 Tar, based on specifications of the Road Board of England and adopted in 1916 by the Engineering Standards Com. of Great Britain.

"GENERAL. This tar is suitable for the surface tarring of roads. (As to the use of this tar for making tar macadam, see Road Board General Directions for Surfacing with Tar Concrete, Sect. 16, Art. 13.)

"HEATING. The tar should be heated to such a temperature that it will reach the road surface in a highly fluid condition. The necessary temperature to attain this end will vary with the mode of application of the tar. The tar should be heated in a heater or boiler specially designed to prevent frothing, which will otherwise inevitably occur if the tar contains even a small percentage of water. The desired temperature will generally be found in practice to be between 104° and 116° C (220° and 240° F) in the heater or boiler.

"SOURCE OF THE TAR. The tar shall be derived wholly from the carbonization of coal except that it may contain not more than 10% of its volume of the tar, or distillates or pitch therefrom, produced in the manufacture of carburetted water-gas.

"SPECIFIC GRAVITY. The specific gravity of the tar at 15° C (59° F) shall be as nearly as possible 1.19, and in no case shall it be lower than 1.16 or higher than 1.22.

"FREEDOM FROM WATER AND AMMONIA. The tar shall be commercially free from water, that is, it shall not contain more than 1% by volume of water or ammoniacal liquor, which water or liquor, if present, shall not contain more ammonia, free or

combined as carbonate or sulphide than corresponds to 5 g of ammonia per gal, or 70 mg per litre, of the tar.

"FRACTIONATION. On distillation in a litre fractionating flask, a distillation flask without special fractionating column, ½ to ⅔ filled, the tar shall yield the proportions by weight of distillates stated below; the temperatures of distillation being read on a thermometer of which the bulb is opposite the side tube of the flask:

Below 170° C (338° F), not more than 1% of distillate, light oils, exclusive of water.

Between 170° and 270° C (338° and 518° F), not less than 16% and not more than 26% of distillate, middle oils.

Between 270° and 300° C (518° and 572° F), not less than 8% and not more than 10% of distillate, heavy oils.

The total distillate between 170° and 300° C (338° and 572° F), shall be not less than 24% and not more than 34%, that is, where the middle oils approach the maximum allowed, the heavy oils should approach the minimum allowed and vice versa.

"NAPHTHALENE. The distillate between 170° and 270° C (338° and 518° F), middle oils, shall remain clear and free from solid matter, crystals of naphthalene, etc, when maintained at a temperature of 30° C (86° F) for ½ hr. This requirement may be waived in the case of tar supplied direct from gas works, but the tar from which the naphthalene has been extracted is preferable to tar containing much naphthalene.

"PHENOLS. The distillate between 170° and 270° C (338° and 518° F), middle oils, shall not yield to caustic soda solution more crude tar acids, phenols, than is equivalent to 3% by volume of the tar.

"FREE CARBON. The tar shall contain not less than 12% and not more than 21% by weight of free carbon. The free carbon is to be determined by the weight of the residue after complete extraction of all matter soluble in benzol or disulphide of carbon. The extraction is best carried out in a Soxhlet or similar apparatus by disulphide of carbon followed by benzol."

British Standard Specification for No. 2 Tar. See note following No. 1 Tar.

"GENERAL. This tar is suitable for making tar macadam, and also may be used for surface tarring in very hot weather when the road crust is exceptionally dry.

"HEATING. For surface tarring, the tar should be heated to such a temperature that it will reach the road surface in a highly fluid condition. The necessary temperature to attain this end will vary with the mode of application of the tar. The desired temperature will be generally found in practice to be between 124° and 138° C (260° and 280° F) in the heater or boiler. The tar should be heated in a heater or boiler specially designed to prevent frothing, which will otherwise inevitably occur if the tar contains even a small percentage of water. For the preparation of tar macadam the tar will not generally need to be heated to so high a temperature as for surface tarring, but the necessary temperature should be determined largely by the sensible heat of the stone treated with the tar, and the mode of application or treatment.

"SOURCE OF THE TAR. The tar shall be derived wholly from the carbonization of coal except that it may contain not more than 25% of its volume of the tar, or distillates or pitch therefrom, produced in the manufacture of carburetted water-gas.

"SPECIFIC GRAVITY. The specific gravity of the tar at 15° C (59° F) shall be as nearly as possible 1.21, and in no case shall it be lower than 1.19 or higher than 1.24.

"FRACTIONATION. On distillation in a litre fractionating flask, a distillation flask without special fractionating column, ½ to ⅔ filled, the tar should yield the proportions by weight of distillates stated below; the temperatures of distillation being read on a thermometer of which the bulb is opposite the side tube of the flask:

Below 170° C (338° F), not more than 1% of distillate, light oils and water, if any.

Between 170° and 270° C (338° and 518° F), not less than 12% and not more than 18% of distillate, middle oils.

Between 270° and 300° C (518° and 572° F), not less than 6% and not more than 10% of distillate, heavy oils.

The total distillate between 170° and 300° C (338° and 572° F) shall not be less than 21% and not more than 26%, that is, where the middle oils approach the maximum allowed the heavy oils should approach the minimum allowed and vice versa.

"NAPHTHALENE. The distillate between 170° and 270° C (338° and 518° F), middle oils, shall remain clear and free from solid matter, crystals of naphthalene, etc, when maintained at a temperature of 25° C (77° F) for ½ hr.

"PHENOLS. The distillate between 170° and 270° C (338° and 518° F), middle oils,

shall not yield to caustic soda solution more crude tar acids, phenols, than is equivalent to 2% by volume of the tar.

"FREE CARBON. The tar shall contain not less than 12% and not more than 22% by weight of free carbon. The free carbon is to be determined by the weight of the residue after complete extraction of all matter soluble in benzol or disulphide of carbon. The extraction is best carried out in a Soxhlet or similar apparatus by disulphide of carbon followed by benzol."

Philadelphia 1917 Specification for Cut-Back Asphalt for Cold Application. "The material shall be a cut-back asphalt prepared in a still by compounding approximately 35% of a distillate with an asphalt meeting the following specifications:

Specific gravity at 25° C (77° F)	Minimum 1.02
Penetration, 100 g for 5 sec at 25° C (77° F)	85 to 100
Volatility, 50 g for 5 hr at 163° C (325° F)	Not more than 8%
Solubility, in CCl_4	Not less than 99%
Ductility, Dow method at 25 °C (77° F)	Not less than 60 cm.

"The distillate shall conform to the following requirements:

Baumé gravity at 15.5° C (60° F)	53 to 60
Specific gravity at 25° C (77° F)	0.76 to 0.73
End point of distillation, test to be made upon 100 cc in a 150 cc Engler flask	177° C (350° F).

"The cut-back asphalt made from a combination of the above two products shall conform to the following tests:

Specific gravity at 25° C (77° F)	Minimum 0.893
Volatility, 20 g for 5 hr at 163° C (325° F)	35% to 40%
Penetration of residue, after volatility	35 to 45
Viscosity, Engler, 50 cc at 25° C (77° F)	275 to 350
Gravity of distillate off below 300° C (572° F),	
Baumé	53 to 60
Specific	0.76 to 0.73."

N. Y. State Highway Comm. 1917 Specification for Oil for Cold Application. "This bituminous material shall have the following characteristics:

1. It shall be free from water.
2. The various hydrocarbons composing it shall be present in a homogeneous solution.
3. It shall have a specific gravity at 25° C (77° F) of not less than 0.93.
4. When evaporated in the open air at a temperature not exceeding 260° C (500° F) until the residue remaining has a penetration, 5 sec, 25° C (77° F), No. 2 needle, 100 g weight, of 10 mm, the amount of residue shall not be less than 50% nor more than 65% of the original oil. At a temperature of 25° C (77° F) such residue shall have a ductility of at least 25 cm, Dow mold.
5. Fifty grams of it upon being maintained at a uniform temperature of 163° C (325° F) for 5 hr, in a cylindrical vessel 5½ cm in diameter by 3½ cm high, shall not lose more than 30% in weight.
6. It shall be soluble in chemically pure carbon disulphide at air temperature to the extent of at least 99.5%.
7. It shall be soluble at air temperature in 76° B paraffine petroleum naphtha distilling between 60° and 89° C (140° and 190° F) to the extent of not less than 80% and not more than 95%.
8. It shall not show more than 10% fixed carbon.
9. It shall show an open flash point of not less than 52° C (125° F).
10. It shall not contain more than 4% paraffine scale."

N. Y. State Highway Comm. 1917 Specification for Oil for Hot Application. "This bituminous material shall have the following characteristics:

1. It shall be free from water.
2. The various hydrocarbons composing it shall be present in a homogeneous solution.
3. It shall have a specific gravity at 25° C (77° F) of not less than 0.96.
4. When evaporated in the open air at a temperature not exceeding 260° C (500° F) until the residue remaining has a penetration, 5 sec, 25° C (77° F), No. 2 needle, 100 g weight, of 10 mm, the amount of such residue shall not be less than 85% nor more

than 95% of the original oil. At a temperature of 25° C (77° F) such residue shall have a ductility of at least 25 cm, Dow mold.

5. Fifty grams of it upon being maintained at a uniform temperature of 163° C (325° F) for 5 hr, in a cylindrical vessel 5½ cm in diameter by 3½ cm high, shall not lose more than 10% in weight.

6. It shall be soluble in chemically pure carbon disulphide at air temperature to the extent of at least 99.5%.

7. It shall be soluble at air temperature in 76° B paraffine petroleum naphtha distilling between 60° and 89° C (140° and 180° F) to the extent of not less than 75% and not more than 90%.

8. It shall show between 6 and 14% of fixed carbon.

9. It shall show an open flash point of not less than 163° C (325° F).

10. It shall not contain more than 4.7% paraffine scale.

11. It shall show a toughness at 0° C (32° F) not less than 20 cm. Toughness is determined by breaking a cylinder of the material 1¼ in in diameter by 1¼ in in height in a Page impact machine. The first drop of the hammer is from a height of 5 cm and each succeeding blow is increased by 5 cm."

N. Y. State Highway Comm. 1917 Specification for Asphaltic Emulsion to be Used Cold in Patching (28b). "The emulsion must be homogeneous. It must mix with water in all proportions. It shall be of such fluidity as to readily flow from bung hole of a barrel. Any material accepted at time of shipment, which should prove to be defective by separation within 30 days after date of delivery, will not be paid for by the Department of Highways, and will remain the property of the contractor except when separation may be caused by freezing.

"When distilled up to a temperature of 204° C (400° F), the total loss shall not exceed 32%. Not over 2% shall be an oil distillate. The residue from the foregoing distillation shall have the following characteristics:

1. It shall have a specific gravity at 25° C (77° F) of not less than 1.01.

2. The penetration shall be between 15 and 25 mm when tested for 5 sec at 25° C (77° F) with a No. 2 needle weighted with 100 g.

3. Its solubility at air temperature in chemically pure carbon disulphide shall be at least 98.5%.

4. The solubility of the bitumen at air temperature in 76° B paraffine petroleum naphtha distilling between 60° and 88° C (140° and 190° F) shall be between 72 and 84%.

5. The bitumen shall show between 10 and 15% fixed carbon.

6. It shall not contain over 1% of ash.

7. It shall not contain more than 2% paraffine scale.

8. It shall have a ductility at 25° C (77° F) of not less than 40 cm, Dow mold."

CONSTRUCTION

6. Mechanical Appliances

The appliances used in the distribution of bituminous materials may be classified as gravity distributors and pressure distributors. As the demand developed for a heavier binder, both for surface treatment and penetration work, machines especially designed for distributing these materials began to appear. The market is supplied with so many different types, that a thoro investigation should be made preceding the purchase of a machine.

The following factors should be given consideration when selecting a distributor: (1) Character and range of work upon which the distributor will be used; (2) present and probable requirements in specifications pertaining to type and details of distributors and the work to be done; (3) different types and grades of bituminous materials which the machine will distribute, and the range in the amount per square yard which can be applied; (4) gravity or pressure distribution, and, if the latter, the range in pressure per square inch; (5) method of controlling uniformity and amount of distribution; (6) accessories of distributors for heating material, recording temperature of bituminous material, amount in tank, and amount of pres

sure, and shutting off bituminous material at end of run; (7) width of distribution and means for modifying same; (8) motive power; (9) width of tires and loads per linear inch of tires when tank is full; (10) ease of operation and repair; (11) structural strength; (12) amount and character of labor required to efficiently operate the distributor; (13) economics, including overhead, operation and maintenance charges.

Gravity Distributors. In this subdivision will be considered pouring cans, tanks with hose attached, and distributing machines.

Pouring Cans. With the use of pouring cans alone it is difficult to secure uniform application of the bituminous material. If the application of the material is immediately followed by vigorous brushing with fiber push brooms, very satisfactory surfaces can be obtained. The use of these methods will result in a high labor cost due to two factors, the high cost of labor, especially in the United States, and the slow progress made. Cans should be used with which may be secured the maximum uniformity of application attainable by this method of distribution.

Reservoir Brooms have been used for superficial treatments to a limited extent in England. The apparatus comprises a kettle in which the material is heated and to which are fitted two lines of flexible hose, each of which is attached to the head of a hand push broom. The tar flows thru the flexible hose into the heads of the brooms and is then swept into the road by the men operating the brooms. One man pulls the tar kettle, two work the brushes behind the kettle and a fourth man supplies the kettle with tar.

Hand-Drawn Gravity Distributors. The advantages of hand-drawn distributors over pouring cans are the more uniform distribution of material, the elimination, to a certain extent, of the personal equation, more rapid work, and the practicability of keeping the bituminous material at a higher and more even temperature. A hand-drawn gravity distributor was introduced in France in 1903.

Tanks with Hose Attached. If a tank from which the bituminous material flows by gravity thru a hose and nozzle onto the road is used, brushing is necessary to secure satisfactory distribution.

Machines with Distributing Apparatus. Watering carts were first used in the United States for distributing the light oils and tars for suppressing the dust. The ordinary spray attachments on the carts were not very satisfactory for distributing this class of material. Attention was then directed to modifying the distributing device, still using the wooden-tank wagon. Practically all of the modifications consisted in substituting for water sprinklers one or more horizontal pipes pierced with small holes. These pipes were attached to the outlet pipe of the tank and were placed parallel to the rear axle at the back of the tank. The pipes were usually about the same length as the gage of the rear wheels. The material flowed thru these pipes in small vertical streams onto the road surface. Hence, in distributing small quantities, the road surface would not be entirely covered with the material. Traffic worked the material around on the road surface so that in the course of time a fairly satisfactory result might be obtained. In some American machines, the material flows from pipes onto a flash board and from the board to the surface of the roadway in the form of a sheet. The general practice in Europe in using machines of this type is to follow the distribution by brushing the material into the road. This is done either by hand brooming or by brooms which are attached directly behind the distributor. The brooms are either of the drag or rotary type. The machines are made to be drawn by hand or by horse.

Pressure Distributors. The various types of distributing machines of this class may be grouped in the following subdivisions: Hand-drawn distributors; pressure tanks to which are attached hose and spraying devices or horizontal distributing apparatus; and machines equipped with mechanical power-pumps between the tank and the distributing apparatus.

Hand-Drawn Pressure Distributors. The European machines of this type have capacities of from 50 to 320 gal. Essentially these machines consist of a tank for holding the material, the tanks being heated by direct fire, a semi-rotary pump with a length of suction hose attached to the tank for the purpose of filling the latter and another pump attached to the tank by which it is possible to generate a pressure between the pump and the nozzle. The material is pumped from the tank thru a length of flexible hose to the outlet end of which is fixed an iron pipe fitted with one or more nozzles. The nozzle is of such a form that the material is thrown in a fine cone-shaped spray. When five or six nozzles are used, they are sometimes so arranged that a 2 ft width of surface can be covered at a time, the nozzles being fixed to a pipe on two small wheels. When one or two nozzles are used the distribution is effected by passing them over the road-surface, the pipe being held up by the men. Both the pump for filling and that for pressure are operated by hand, hence it takes at least two men to operate this type of machine, one to run the pressure pump while the other manipulates the hose. In one type of American machine the heated material is pumped into the distributor and applied to the roadway surface by pressure from a tank of compressed air. In other types, the pressure is obtained from hand or small gasoline pumps. These machines are especially useful in connection with maintenance work.

Pressure Tanks. These machines consist of steel tank wagons equipped with steam coils and with either a flexible hose with a nozzle attached or a system of pipes equipped with nozzles. The tanks are hauled by a steam roller which supplies steam for heating the material in the tank and furnishes the steam for the pressure. The bituminous material is forced out by the pressure of the steam between the material and the top of the tank.

Flexible Hose Apparatus. By an arrangement of the piping system, means are provided at the outlet valve of the tank so that the steam can be admitted to either side of the valve. The hose can be easily and thoroly cleaned out before the distribution of the bituminous material is commenced by simply allowing hot steam to pass thru the same. Several types of nozzles have been tried. The best nozzle is cast in such a form that the material is given a twisting motion just before it leaves the nozzle, resulting in a cone shaped spray. Two men are generally used with this machine besides the man on the roller. One man is at the nozzle end of the hose, and the other clasps the hose about midway of its length, and drags it around as the nozzle man distributes the material.

Pressure Distributors Equipped with Air Compressors. Some American distributors efficiently utilize pressure from air compressors. Steam is delivered to the compressors either from a boiler mounted on a distributor or from a steam roller or tractor. By the passage of steam thru a system of pipes, the bituminous material is heated to the desired temperature. The material is distributed thru either one or two horizontal pipes equipped with nozzles.

Pressure Distributors Equipped with Mechanical Power Pumps. Several pressure machines of this type have been invented in the United

States. The distributing devices of all of these machines are alike in having horizontal pipes fitted with nozzles. The machines differ somewhat in the way the pressure is obtained and applied. Pumps, run by a sprocket-drive attachment on the rear axle, by steam, and by gasoline, are utilized. Horses and steam rollers are used for hauling. Some distributors are mounted on motor trucks.

Am. Soc. Mun. Imp. Specification for Pressure Distributor for Surface Treatments. "The pressure distributor employed shall be so designed and operated as to distribute the refined tar specified uniformly under a pressure of not less than 20 lb nor more than 75 lb per sq in in the amount and between the limits of temperature specified. It shall be supplied with an accurate stationary thermometer in the tank containing the refined tar and with an accurate pressure gage so located as to be easily observed by the Engineer while walking beside the distributor. It shall be so operated that, at the termination of each run, the refined tar will be at once shut off. It shall be so designed that the normal width of application shall be not less than 6 ft and so that it will be possible on either side of the machine to apply widths of not more than 2 ft. The distributor shall be provided with tires of widths dependent upon the following relationship between the pressure per square inch of tire and the diameter of the wheel; for a 2-ft diameter wheel, 500 lb shall be the maximum pressure per lin in of width per wheel, an additional pressure of 30 lb per in being allowed for each additional 3 in in diameter."

Mass. Highway Comm. Equipment by Farrington (30a). "As to equipment, for handling the lighter grades of bituminous materials, one or two distributor carts and a pump for transferring these materials from the tank-cars are required, and there should be a tool-house, also tents for the laborers, unless vans are provided.

"For handling the heaviest grades of oil or tar used for surface work, the following plant is needed: 1 10- or 12-ton steam roller; 1 portable heating boiler, 1 steam pump, 2 steel tank-wagons, 1 pressure distributor, if mounted separately, or 2 if attached to the tank-wagons; 1 or 2 watering carts; 1 2-horse sweeper; 1 portable tool-house, and 2 large tents or vans for laborers.

"As to distrib tors, for handling the road oils or the corresponding grades of tars, a gravity machine may be used with good results, if the bituminous material is broomed after it is applied; but the cost of distribution will be less and the results more satisfactory if a pressure distributor is used. For this work, a distributor cart with a pump mounted on a frame back of the tank and connected by chain with a large sprocket bolted to one of the rear wheels is most satisfactory. Under favorable conditions, good results have been obtained with gravity m chines in distributing even the heaviest grades of bituminous materials for surface work; but the chances of failure, if the conditions are not favorable, are such that they should always be applied by pressure distributors if possible. The distributor just described, or one with a gas-engine pump mounted either on the tank-wagon or on separate gear, may be used, but one operated by steam will give the best results. One advantage of the steam distributor is the possibility of cleaning out the pipes and nozzles by blowing steam thru them. Of the steam distributors, there seems to be little choice between the one using the direct pressure of steam in the tank for distributing and the pump type, each having its advantages."

7. Methods of Construction

Preparation of Surface of Wearing Course. Before constructing a bituminous surface on a broken stone or gravel road, every precaution should be taken to secure the best sub-drainage which is practicable under the local conditions. All depressions, pot-holes, ruts, or other irregularities should be filled with thoroly compacted bituminous-coated stone so that the whole surface of the roadway is even. All surplus dust must be removed so that the larger pieces of broken stone of the roadway surface are exposed but without breaking the bond. This cleaning process is accomplished by the use of horse sweepers and fine bass brooms, with coarse fiber brooms and fine bass brooms, or by a vacuum process. If there is caked mud on the surface of the roadway, wet brushing will prove advantageous.

If a bituminous surface is to be constructed on a new broken stone or gravel road, or on one which has just been resurfaced, the bituminous material should not be applied until the crust has had time to consolidate under the action of traffic and with the aid of the binding action of dust and moisture. The length of the period which should elapse before the application of the bituminous material depends upon the kind and amount of traffic, the character of the crust, and the time of the year when the roadway is completed. For example, this period must usually be short, if the roadway is composed of trap rock, is completed in August and is subjected to a traffic of more than 300 high-speed motor vehicles per day; otherwise the roadway will ravel due to the particles of the crust not being thoroly bound together, dry climatic conditions and the disintegrating effects of the traffic. If, on the other hand, the roadway of a residential street was constructed of trap rock in June, and was subjected to local traffic, treatment with a bituminous material probably could be postponed for 1 year. If it is impracticable to postpone the surface treatment, special care should be taken to secure a maximum consolidation of the crust of the roadway by puddling and rolling.

Effect of Size of Road Metal of Wearing Course. It is apparent that the character of the cleaned surface will be affected by the method which was used in the original construction of the roadway. If the practice of French engineers in using large-size stone varying from 1 to 2½ in in longest dimensions for the top course of a broken stone road is followed, and the stone is hard and tough, the desired surface can be easily secured. The surfaces of the large stones in such a roadway are easily cleaned by brushing without the dislodgment of stones in the surface. A clean mosaic surface is of the utmost importance from the standpoint of the formation of a satisfactory bond between the broken stone and the bituminous material. The maintenance of bituminous surfaces on wearing courses of large broken stone is economical, since after the bituminous surface wears away in spots, the mechanically interlocked large stones will of themselves generally have sufficient stability to withstand the effects of traffic until retreated.

On the other hand, if the top course of a broken stone road has been constructed of a product varying in size from ¼ to 1¼-in material, it will be very difficult, if not impossible, in the case of soft stone, to secure an even, clean surface. Even after thoro brushing, a film of impalpable dust usually covers the surface of the roadway. During hard brushing small depressions will probably be formed by the displacement of pockets of dust and the smaller sizes of stone. Furthermore, the wheels of vehicles may adhere to the bituminous material and thus tear up the small mineral matter adhering to it. As soon as the bituminous surface wears out in spots, rapid disintegration of the exposed broken stone or gravel surface, with the consequent formation of pot-holes, is apt to occur.

Dry and Damp Roadway Surfaces. When the bituminous material is applied the roadway surface should be bone dry. If the surface is damp it will be difficult to secure a good bond. If the surface is slightly damp when asphaltic oils or tars are applied without being heated, some engineers believe that better results may ensue because, in their opinion, a more even distribution and adhesion of the material are obtained than when the surface is dry.

Richardson (16c) offers the following explanation in support of the contention that oil adheres better to the surface of a watered macadam road than to a dry road. "There is always a slight coating of dust adhering to the surface stone, which pre-

vents adhesion. If, however, the surface is sprinkled before the application of the oil, it converts this dust into a paste. The dust is the detritus of the rock, and, like clay, it is more or less colloidal. The result is that the dust in this condition will emulsify with the oil when the latter is applied to the surface and will mix with it so readily that the bitumen will come in contact with the rock, and, after the evaporation of the water, will adhere perfectly. Clay and water will mix with any kind of asphaltic oil, and with the greatest facility. A great deal of it has been used on roads in Germany for distributing oil as an emulsion. The clay and water are mixed with the oil, put into the watering-cart, and sprayed on the road."

Conclusion, Am. Soc. C. E. Spec. Com. Mat. Road Cons. (16f). "The success of surface applications is proportionate to the adhesion obtained by the bituminous material to the old roadway surface, and such degree of cleanliness of the latter must be had, by means of sweeping or other methods, as will insure a proper degree of adhesion. The roadway surface should be dry when the bituminous material is applied."

Methods of Application of Bituminous Materials. Distribution of the bituminous material is accomplished by two methods. Flow by gravity is utilized in one method and mechanical pressure in the other. The use of gravity distributors has not been developed to its fullest extent in America, in that the use of mechanical brushes or the brushing of the material into the road by hand brooming has never been adopted extensively. By brushing after gravity distribution, it is possible to distribute uniformly 1/4 to 1/5 gal per sq yd of many of the bituminous materials used for the construction of bituminous surfaces. In some cases, when the distribution is accomplished by hand brooming, the adhesion of the material to the road metal is as good as when the material is applied under pressure. The advantages claimed for pressure distributors are: Aid in cleaning the surface of the roadway, even application, distribution of small amounts per square yard, satisfactory adhesion obtained between the bituminous material and the surface of a clean, dry roadway, and rapid and economical distribution.

Conclusion, Am. Soc. C. E. Spec. Com. Mat. Road Cons. (16g). "The bituminous material, in all cases, should be applied by a pressure distributor designed so that the material will be spread uniformly and with a pressure of not less than 20 or more than 75 lb per sq in."

Fulweiler (16c) has presented the following discussion relative to pressure distribution: "If a heavy pressure is used, it will apparently atomize the bituminous material, and when this happens, it ceases to strike the road with that necessary, directional velocity which blows the dust away as the material is distributed. The nozzles of the machine with which the speaker is most familiar are similar to the flat top Bray burners used for illuminating gas. As they leave this nozzle the two streams of material impinge on each other and form a flat sheet or spray of material at right angles to the original plane of the two streams. The amount of pressure used modifies the shape of the spray. As the pressure is increased the sheet of material strikes the road with increasing force, and blows the dust from the surface very effectively. If the pressure is increased still further, a point will be reached that will cause the lower edges of the spray to open or separate, and at this point the material has become atomized. From this point a further increase in pressure will more completely atomize the material until finally it is all in that condition as it leaves the nozzle and reaches the road in minute drops rather than a solid sheet, actually defeating the desired scrubbing action on the surface."

Crosby (16c) states that "The adhesion of a bituminous material to a stone or concrete surface may be increased by the use of a pressure distributor. The pressure machine seems to act like the cement gun when used on dirty steel, because the sand blown thru the gun against the steel cleans off the dirt and allows a good adhesion of the cement. In the same way, the pressure distributor seems to obliterate the dust film, between the stone or concrete and the pitch, which nullifies the adhesiveness of the latter; at least, where it has often been difficult to obtain adhesiveness under a gravity application, the results have been entirely satisfactory where the same materials have been applied under pressure."

Amount of Bituminous Material. As a general rule from ¼ to ½ gal per sq yd is used for the first treatment, preferably in two applications. The amount applied per treatment depends upon the kind of bituminous material, the character and condition of the surface, and the details of the method of application. For example: A smooth surface composed of large sized, tough, hard stone and well compacted by traffic, would require from 0.25 to 0.35 gal; for a somewhat rough surface of stone having a medium toughness and hardness and recently resurfaced, it would be necessary to use from 0.35 to 0.5 gal per sq yd to form a satisfactory thin bituminous surface.

Penn. State Highway Dept. Practice by Biles (17). "The following is intended as a guide for the amount to be used under various conditions: If the surface of the road is made up of pieces of ballast size stone (2 to 3-in) from which traffic has removed all the fine material, leaving large surface voids between the stones, enough of the bituminous material must be applied so that it will flush up level to the top of the large pieces of stone and firmly bind in the chips and gravel which will lay in the crevices between the stones. If, on the other hand, the surface of the road is equally clean, but traffic has not removed the fine particles between these stones to the same extent and the crevices between them are consequently smaller, then a somewhat smaller amount of bituminous material should be used, since an excess will again flow off the road. In treating a road which has recently been resurfaced, it will be found often that even after all the screenings and fine materials have been swept from the top of the road leaving the large stones bare, there will still be a certain amount of dust and fine material between the stones which had not yet been compacted thoroly by traffic and which will absorb the bituminous material like a blotter, leaving only a brown stain in these spaces. In such cases, the amount of application must be increased until this fine material is well saturated and there is enough of the bituminous material near the surface of the road to bind thoroly the covering of the chips or pea gravel."

Fulweiler (16c) states that "When the steel-tire traffic becomes pronounced on a road or street, the thinnest possible surface treatment seems to give the best results. If it is attempted to apply a cold material with a gravity distributor, it is very difficult to put on much less than ½ gal per sq yd. If a pressure distributor is used, a very much smaller quantity can be applied. If a total of about ⅜ gal per sq yd is put on in three separate applications, the result is apparently quite as desirable as with the single application of ½ gal with the gravity sprinkler, and it is much more uniform. In this way, if a spot is missed on the first application, the second treatment covers it, or if it is missed on the second treatment, the third treatment covers it. By applying three coats and by allowing 8 or 10 hr for each coat to set, the best results are obtained, and ⅛ gal per sq yd is saved. It does not cost any more to apply the material in this way; it simply means that the distributor is driven over a greater distance, and the actual time consumed in applying the material is not the important factor. The time is lost mainly in loading the distributor, hauling it to the road, and getting it ready for work."

Application of Top Dressing. The superficial coat of bituminous material is usually covered with either coarse sand, fine gravel, or stone chips varying from ⅛ to ½ in in longest dimensions. Material containing clay should not be used as disintegration may result by the emulsifying of the clay and water on the bituminous surface. The amount of sand, stone chips, or gravel used per square yard depends upon the quantity and kind of the bituminous material, and the character of the surface of the roadway. From 5 to 22 lb per sq yd have been used satisfactorily for thin bituminous surfaces: 5 to 12 lb for from 0.1 to 0.25 gal per sq yd of bituminous material; 10 to 17 lb for 0.25 to 0.35 gal; and 15 to 22 lb for from 0.35 to 0.5 gal.

Top dressing is distributed by hand and machine methods. In the machines employed for this purpose, the mineral matter falls on a revolving cone beneath the body of the wagon and is thus uniformly spread over the surface. If the covering is distributed by hand, the material should be placed in piles from 25 to 50 ft apart alongside the roadway prior to the

application of the bituminous material. A gang of 10 spreaders working efficiently can cover from 12 000 to 20 000 sq yd per day of 8 hr.

Penn. State Highway Dept. Specifications for Covering Material (17). "Pea gravel shall be composed of hard, tough, durable pebbles, free from loam, silt, clay or other foreign substances, and 100% shall pass thru a ½-in screen: 35 to 50% shall pass thru a ¼-in screen; 10 to 20% shall pass thru a ⅛-in screen; and not over 10% shall pass thru a 10-mesh sieve.

"Stone chips shall consist of trap rock or other approved stone equally as hard, tough and durable, newly broken, with sharp edges, and of uniform quality thruout, free from dirt or disintegrated stone or screenings or other foreign matter. They shall be of such size as to pass a ⅝-in screen, with the larger sizes predominating, and shall be free from dust."

Conclusion Am. Soc. C. E. Spec. Com. Mat. Road Cons. (16g). "After the bituminous material is applied it should be covered immediately with the toughest grit obtainable that will pass thru a screen with openings not less than ⅜ in nor greater than ⅝ in, just enough of such material being used to cover the bituminous material. It is advantageous, but not entirely necessary, to roll with a steam roller after the application of the grit."

French Practice of Constructing Tar Surfaces on Broken Stone Roads (55), as reported to the 3rd Int. Road Cong., is as follows:

It consists of spraying during dry and hot weather the previously clean-swept road with fluid tar heated to 70° C (158° F) at least, or with a heavy tar oil from coal. The tar penetrates into the joints of the stone and incorporates itself with the road to a depth not exceeding 2 to 3 cm (0.8 to 1.2 in). The dressing of tar per sq m varies from 0.8 to 1.5 kg (1.34 to 2.5 lb per sq yd) or even more, up to 2.5 kg (4.2 lb) in certain cases, the heavier dressing being in the case of original tarring, and the lighter in the case of subsequent maintenance.

British Practice of Constructing Tar Surfaces on Broken Stone Roads is fully covered in the specifications (see Art. 8) adopted by the Road Board of England.

Connecticut Practice in the Construction of Asphaltic Oil Carpets on Gravel Roads by C. J. Bennett, Highway Commissioner. " Bituminous carpets on gravel roads are of two classes, applied cold or hot. It may be, however, assumed that for a gravel road carefully built, a cold treatment either of oil or tar will give better results than the hot treatment, since the treatments may be more frequently renewed and a great number can be made before the road needs reconstruction. On the other hand, a hot carpet is of itself more stable and will last a considerable length of time. Any of the bituminous carpets, however, are liable to roll up and mud up in wet weather and should be only used with great care, particularly as to the character and amount of material applied and the method of application. In no case, should the amount exceed ¼ gal per sq yd of surface treated per application. It is far better to make repeated applications than to put on too much at once. These carpets should be covered with proper clean covering material, either sand, coarse sand, gravel or stone chips in such a manner as to completely cover the surface of the road and to provide sufficient material so that the bituminous material contained in the carpet should not exceed 15% by weight of the total carpet covering. Care should be taken that a proper bond is formed between the carpet and the road body. This may be done by sweeping exceedingly clean."

Mass. Highway Comm. Sand and Oil Layer Method of constructing a bituminous surface on a roadway of sand is described in detail in the specifications contained in Art. 8.

The Commission states (43) that "these can be used only where a sand of the right quality is available, and under present methods can be used only where the traffic is mostly light teams and automobiles; they will not stand up if they are used

by many heavily loaded teams every day. The layer roads are more easily rutted by teams than are the mixed roads, for two reasons: First, one cannot use as heavy a quality of asphaltic oil because it cannot be made to mix with the cold sand; second, because by the layer method one can never secure as even a mixture of the sand and oil on every part of the road.

"The traffic that has been carried successfully as shown by the traffic census taken in 1909, 1912 and 1915 is about as follows, the figures being the average daily traffic: Eastham, 1905 road, layer method; 20 heavy teams, 17 light teams and 258 automobiles."

Maryland Method of Constructing Large Mileage Under One Contract, as described by Fulweiler (16e), is as follows:

"In the organization for re-surfacing, where a considerable amount of this work is to be done, attention is called to a plan by which a very large amount of such work has been done on the State roads in Maryland. Under this plan the State furnishes and applies the necessary stone covering, purchasing the stone and having it delivered in piles along the road-side in the early spring, when the price of teams is quite low. From a schedule prepared by the State engineers, showing the location of the roads to be treated, a price is agreed on, and a contract drawn up whereby the manufacturer of the material agrees, for a unit price per square yard, to sweep surfaces which have been previously treated with bituminous material, and also surfaces which have not been thus treated, and a unit price per gallon for applying the material, at the approximate rate shown on the schedule. In the contract for 1913, it was specified that all work should be completed before July 31, with a penalty clause of $25 per day for every day that this time was exceeded. There was a further clause in which the company agreed to pay the State $25 per day for every day that it was delayed thru breakdowns or the failure of material to arrive, and the State agreed to pay the company the same amount for every day that it delayed the application of the material thru inability to cover it. This contract involved some 34 pieces of road in nine counties of the eastern shore of Maryland, amounting to about 118 miles, and containing 976 071 sq yd. On this was applied 342 785 gal of material, at a rate varying from 1/8 to 1/2 gal per sq yd, and averaging 0.366 gal per sq yd. This was covered with stone chips averaging 12 lb per sq yd.

"Two motor trucks were used in this work, and they arrived about May 26th, altho, owing to bad weather and some delay in organizing the gangs, work was not commenced until May 28th. One truck finished practically half of the work on July 18th, and the other finished on July 30th. The State maintained two gangs, of 12 men each, each under an inspector, for applying the stone chips, the company sweeping the roads and furnishing and applying the binder.

"Practically this same form of contract had been in force during 1912, but during that year the work was not laid out according to schedule, and the trucks frequently had to make long jumps between the different pieces of work. This caused considerable loss of time, which was furthermore augmented by difficulty in securing proper labor. As the result of the experience of 1912, the work was laid out more systematically in 1913, and men composing the covering gang in one case were held thruout the season. The effect of having experienced men for covering is well brought out in the following table, which summarizes the operations of the 2 years, the time being given in truck-days. In 1913 the decrease in time lost in transit, repairs, and delays, is quite striking, as is the average increase in the quantity applied per day." See Art. 8.

	1912	1913
Sunday and holidays	21	20
Repairs and delays	22	6
Rain	5	9
Transit	34	18
Applying material	57	72
Total elapsed days	138	125
Percentage of days worked	66%	72%
Percentage of days material applied	41.5%	57.5%
Average number of gallons applied per day	2 860	4 760
Average number of square yards treated per day	8 230	13 550

8. Specifications for Construction

Am. Soc. Mun. Imp. 1917 Specifications for Hot Tar Surface Treatments, are as follows:

"**Description of Bituminous Surface.** The bituminous surface shall consist of one application of refined tar covered with a layer of No. 1 broken stone (passing thru ⅝-in and over ¼-in screen) constructed as hereinafter specified.

"**Refined Tar.** Refined tar used in the construction of the bituminous surface shall conform with either one of the specifications covering the chemical and physical properties of refined tars included under the item entitled 'Refined Tars for Surface Treatments.' See Art. 5.

"**Heating Refined Tar.** The refined tar shall be heated in kettles or tanks so designed as to admit of even heating of the entire mass, with an efficient and positive control of the heat at all times. It shall be heated as directed by the Engineer to a temperature between 93° C (200° F) and 121° C (250° F). All refined tar heated beyond 121° C (250° F) shall be rejected. No tar shall be heated in kettles or tanks containing any oil or asphalt cement. Before changing from one type to another, kettles or tanks shall be scrupulously cleaned in order to avoid mixtures of the two. Any mixtures of different kinds of bituminous materials shall be rejected.

"**Thermometers Furnished by Contractors.** The Contractor shall provide a sufficient number of accurate, efficient, stationary thermometers for determining the temperature of the refined tar in kettles or tanks.

"**Preparation of Surface of Road.** Prior to the application of the refined tar, the surface of the broken stone road, when thoroly dry, shall be swept clean of all dust, dirt or other loose material with horse or power-drawn brooms and bass or other fine fiber brooms, or with stiff fiber hand brooms and bass or other fine fiber brooms, as directed by the Engineer. When the cleaning is completed the upper surface of the No. 3 broken stone (passing over 1¼-in and thru 2¼-in screen) shall be exposed, forming a clean mosaic surface.

"**Application of Refined Tar.** After the surface shall have been cleaned to the satisfaction of the Engineer, and when thoroly dry, the refined tar shall be uniformly applied over the prepared surface of the road by means of a pressure distributor as hereinafter specified (see Art. 6) and in accordance with the directions of the Engineer. The refined tar, when applied, shall have a temperature between 93° C (200° F) and 121° C (250° F). The total amount of refined tar to be used in the construction of the bituminous surface shall be applied in one application and shall not be less than ¼ nor more than ½ gal per sq yd, the precise quantity being determined by the Engineer.

"**Application of No. 1 Broken Stone.** Immediately after the application of the refined tar, a layer of dry No. 1 broken stone, not to exceed ⅜ in in thickness, shall be spread and broomed as directed by the Engineer over the surface of the refined tar and shall be at once rolled as directed by the Engineer with a roller weighing between 8 and 15 tons.

"**Seasonal and Weather Limitations.** No refined tar shall be applied when the air temperature in the shade is below 10° C (50° F), except by the written permission of the Engineer.

"**Measurement and Payment.** The quantity of broken stone road with bituminous surface to be paid for under this item shall be the number of square yards, measured horizontally, satisfactorily completed in accordance with the specifications. The price stipulated in this item shall include the furnishing, crushing and screening of the different sizes of broken stone, the placing, rolling and watering of the broken stone, the heating and distributing of the refined tar, and all materials, work and expenses incidental to the completion of the broken stone road with bituminous surface except the furnishing of the refined tar, which will be included for payment under the item entitled 'Refined Tars for Surface Treatments.'"

The General Directions and Specifications Relating to Hot Tar Treatment of Roads, Adopted by the Road Board of England, are as follows:

"1. Surface tarring may be advantageously applied either to an old road surface in good condition or to a new surface after it has been consolidated and dried, but the tarring should never be carried out unless the road is thoroly dry. If there are any depressions, pot-holes, waves, grooves, or other irregularities, these should, as far as practicable, be made good before tarring is commenced, so as to provide an even surface.

2. Painting and spraying machines get thru the work of tarring more rapidly than application by hand, and consequently are to be recommended, but hand work gives satisfactory results, and the selection of the method to be employed must be largely determined by the available supply of efficient labor.

3. If it is intended to tar an old surface it is advisable to take advantage of the early months of the year to scrape or brush the road during wet weather as a preparation for subsequent tarring, and especially to keep the road free from caked mud.

4. If the crust of a road is thin at the sides, but adequate in the center, the sides should be strengthened and consolidated before application of tar to the surface.

5. In resurfacing any road the surface of which is afterwards to be tarred, stone chippings, and not fine material, should be used for binding.

6. The road whilst being tarred should be closed to traffic over half its width, or where practicable, over its whole width.

7. The road should be thoroly brushed and cleaned before application of the tar. Wet brushing should be used sometime previous to dry brushing, if there is any caked mud. Any method of brushing may be used which will scour and clean the road thoroly, the best being horse brushing, followed by hand brushing.

8. Tar should be used for surface tarring which complies with either Road Board Specification for Tar No. 1 or Road Board Specification for Tar No. 2, but if the heavier grade of the tar is used, care should be taken to apply it only when the road is dry and well warmed by the sun's rays, otherwise it will not flow freely. See Art. 5.

9. The tar should be heated to its boiling point at convenient positions on the works, and should be applied as hot as possible, so that it may flow freely. The desired temperature will be generally found in practice to lie between 104° and 116° C (220° and 240° F) for Tar No. 1, and between 127° and 138° C (260° and 280° F) for Tar No. 2.

10. In order that the tar should be applied to the road as hot as possible, it is advisable if the method of application is by hand, to use flexible pipes to convey the tar from the boiler to the point of application. If these are not available it will be found convenient in case of hand pouring, to use 3-gal cans specially constructed for the purpose, fitted with spouts leading direct from the bottom of the cans, and being not less than 1½ in in diameter at the orifice.

11. Immediately on application, the liquid tar should be brushed so far as necessary to ensure regularity in thickness of the coating.

12. The quantity of tar required will vary according to the physical conditions of the road, but generally, in the case of a road to be treated with tar for the first time, the quantity should be 1 gal to coat from 5 to 7 sq yd.

13. If the road must be opened for traffic before the tar has set hard, grit should be spread on the surface to prevent the tar from adhering to the wheels of vehicles, but gritting should be delayed as long as possible, and the quantity of gritting material to be spread should be no more than sufficient to prevent the tar from adhering to wheels. Stone chippings, crushed gravel, coarse sand, or other approved material, free from dust, not larger than will pass thru a ¼-in square mesh should be used for gritting, in quantity not exceeding 1 ton for 300 to 350 sq yd if grit is used, and 1 ton for 200 to 250 sq yd if coarse sand is used.

14. Precautions should be taken to prevent liquid tar passing directly thru drainage gratings or outlets.

15. For the safety of the public precautions should be taken by lighting, watching, and warning. Notice boards should be placed in suitable positions. It is specially desirable to place warning notices at points in the neighborhood of the work where other roads join or cross the road being tarred, to enable motorists and cyclists to avoid the obstructed road by taking any available alternative route.

16. On heavily trafficked roads it is advisable to apply a second coat to either the whole width or from 9 to 12 ft of the center of the road in quantity of 1 gal to coat from 8 to 10 sq yd about 2 to 3 months after the first application.

17. Surface tarring should be renewed annually on all important roads, and as required on roads with light traffic. On such re-coatings the quantity of tar to be applied will vary with the extent to which the previous coating of tar has been removed by weather or by traffic.

18. Two or more samples of the tar used should in all cases be kept in quart tin cans, and be carefully labelled, including particulars fixing the locality or length of the road on which the tar was used. The Road Board will arrange with the National

Physical Laboratory to submit a selection of these samples to a series of chemical and physical tests with a view to the results being recorded for future reference, and surveyors will from time to time be invited to send samples for the purpose.

19. In all cases careful record should be kept of the condition of the road surfaces in winter and summer, both before and after tarring, the quantity and quality of tar used, the superficial area covered, the state of the weather when the work is being done, the time occupied in actual work, and in waiting whilst work is stopped owing to wet weather, the number of men employed, and full details of the cost of labor and material.

20. Surveyors are invited to send records to the Road Board to be classified and published for general information. Forms for these records will be supplied by the Board.

21. Surveyors are recommended to have samples of the tar supplied to them under contracts properly tested by a qualified analytical chemist."

Md. State Roads Comm. 1917 Specifications for Tar and Oil for Cold Application are as follows:

"**Sweeping.** The road surface shall be swept with a rotary rattan broom drawn either by horse or motor power in such a manner as to remove from the surface all dirt or other foreign materials, and should the rotary sweeper not remove all the dirt or foreign material, giving a clean surface, then the contractor will be required to scrape the foreign material from the surface with hoes or other tools, and cleanly sweep it with rattan brooms by hand.

"**Applying the Material.** No material shall be distributed except by a motor-drawn pressure distributor of a type satisfactory to the engineer, and no material shall be applied when the surface is wet, frosty, or when, in the opinion of the inspector it is unfit to receive the application. All material will be applied at the rate specified by the inspector, but in no case is more than ⅓ gal of material to the square yard to be applied to the surface in one application and where ½ gal per sq yd is applied, it shall be put on in two applications. When two applications are specified, all the stone chips shall be evenly and uniformly distributed over the surface as hereinunder specified, after the first application of oil or tar has been made, and then the second application shall be made, but in no case shall more than 24 hr elapse between the first and second application of the oil or tar. In order that the traveling public may be accommodated as much as possible, the contractor will apply the oil to one-half of the road surface at a time, and as soon as one truck load is applied to one side of the road it will be covered with chips by the contractor or the State, as the contract provides.

"The contractor will so arrange his work that the distributor will be on the road ready to spread oil or tar by not later than eight o'clock in the morning, and should the contractor at any time refuse or neglect to be ready to spread oil or tar by eight o'clock in the morning, when the spreading of the stone chips is being done by the State Roads Comm., then the contractor is to pay the State Roads Comm. $3 per hr or fraction thereof for all delays due to this cause. Should the State Roads Comm., on account of not having sufficient men to spread the stone chips, delay the contractor in spreading oil after eight o'clock in the morning, then the State Roads Comm. will pay the contractor $3 per hr or a fraction thereof, for all time due to such delays, but it is clearly understood that the contractor will so arrange his work that the oil or tar applied can be covered with stone chips by the close of the working day in that locality unless otherwise authorized by the inspector.

"**Spreading Stone Chips.** The stone chips or gravel required to be spread on the road after the application of the oil by the contractor will be deposited along the road on one side or the other in approximately even piles, at regular intervals of 25 ft. These chips or gravel will be funished in these piles by the Commission without expense to the contractor. Approximately 80 tons will be used to a mile of 14 ft surfacing to be treated. The contractor will bid a price per ton for the chips spread on the road from the piles. Railroad weights will be used as a basis of payment in all cases where the material is hauled on the railroad and quarry weights when hauled direct from the quarry to the road.

"The contractor will be required to spread these chips or gravel evenly and uniformly over the surface of the road immediately after the oil is applied and fill in all holes or inequalities, and in no case must more than 2 hr elapse between the application of the oil and the complete covering of the surface with chips or gravel, and under no circumstances will work be permitted to remain uncovered during the night, and the contractor must so arrange the application of the oil so that all the surface can be com-

pletely covered with chips or gravel during the working day. The term 'evenly and uniformly' shall be construed to mean that each and every square yard of surfacing shall have the same amount as each other square yard within a variation of not more than 10%, except in such places as the inspector may direct to fill depressions or holes."

The Los Angeles 1917 Specifications for the Construction of an Oil Carpet on Street Roadways are as follows:

"Where there are cement or brick gutters, a small trench not more than 1 in in depth at the outer edge of the gutter, shall be trimmed out to meet the surface at a point not more than 6 in from the edge of the gutter, and a small ridge of sand or screenings shall be maintained on the outer edge of the gutter to keep oil from running on the gutter. This ridge shall be removed after the oiling is completed.

"Oil shall then be evenly distributed over the entire surface of the roadway in a volume equal to 1 gal by measure per sq yd of surface. After a lapse of not less than 24 hr, sand of a quality hereinafter specified, shall be uniformly spread upon the oiled surface in such quantity as will absorb all surplus oil. The roadway shall then be brought to a smooth and even surface by use of hand brooms or rakes, and all surplus material shall be swept from the street.

"Oil shall again be distributed over the surface as before in a volume equal to ½ gal by measure per sq yd of surface. After a lapse of not less than 24 hr sand shall again be spread upon the oiled surface and the road-bed brought to an even surface, as hereinbefore specified. The surface shall then be rolled with a roller having a compression of at least 200 lb per in width of tire, until it has received the utmost compression possible and is uniformly smooth and free from bumps, sags or loose spots. The surface of the road during rolling shall be sanded and swept whenever necessary to secure a uniform coating of oil and sand, and on completion of the rolling the street shall show no stickiness.

"The total amount of oil used shall not be less than 1½ gal per sq yd of the roadway surfaced. In the process of oiling care must be taken not to soil the curbs or walks. After the oiling of a roadway has commenced, it shall be carried on diligently to its completion. Oil shall not be applied to the surface of a roadway while it is in a wet condition.

"After the final rolling, the road-bed shall be trimmed wherever necessary and sand shall be distributed thereon and brought to a smooth and even surface 1 in in thickness by the use of hand brooms or rakes.

"Oil shall be applied in a uniform sheet by means of pressure distributing sprays only and shall be at such temperature within the limits hereinafter specified as is determined by the inspector to be desirable. The pressure sprays shall be operated at a uniform pressure of not less than 20 lb per sq in. Oil wagons or trucks shall be provided with tires of such width that the maximum pressure on said tires shall not exceed 400 lb per sq in of tire."

Mass. State Highway Comm. Specifications for Sand and Oil Layer Work (30b) are as follows:

"Grading. The road shall be graded for a width of 21 ft in cuts and 25 ft on fills. The slopes outside the graded roadway shall be left in a neat condition.

"Subgrade. Any clay or other material in the subgrade which, if left, would cause frost action detrimental to the road surface, shall be removed to the depth ordered by the engineer and replaced with suitable material, and any sandy places shall be hardened as ordered. For this purpose, sandy loam or clay may be used, but if used, only enough of these materials shall be placed on the subgrade to carry the travel while the surface is being formed, and in no case shall the depth of such hardening material exceed 3 in after rolling. The subgrade shall be shaped to correspond with the proposed cross-section of the finished road and shall be rolled with a horse roller, unless otherwise ordered.

"Application of Oil. On the roadbed prepared as hereinbefore described, asphaltic oil shall be applied for a width of 15 ft, unless otherwise ordered. The oil shall be shipped to the nearest railroad freight station in tank cars and transported to the work in suitable distributor carts. It shall be heated in the tank cars or distributor carts, so that when applied it shall have a temperature of not less than 82° C (180° F) nor more than 121° C (250° F). The oil shall be applied to the road by a pressure distributor which will spread it evenly over the surface, leaving no spots or streaks uncovered, and no overlapping will be allowed. The distributor shall be so arranged that the operator can control the flow and can cut out sections so as to vary the width

of the road covered. If 2 gal of oil per sq yd are to be used in forming the surface, the oil shall be distributed in 3 applications of approximately ⅔ gal per sq yd. If 1½ gal are used, there shall be two ¾-gal applications.

"Construction of Sand and Oil Layers. Immediately after the oil is applied, a uniform layer of sand shall be spread over it, the depth of the sand to be approximately 1¼ in for the ⅔-gal application, and 1½ in for the ¾-gal application. Each layer of sand and oil shall be rolled with a horse roller, and if ordered, the road, before its acceptance, shall be rolled with a steam roller. During the rolling, sand shall be applied to absorb any oil flushing to the surface. Each layer of sand and oil shall be allowed to stand a sufficient length of time so the oil will mix with the sand, and there shall be no surplus sand or free oil on the surface when the next application of oil is made.

"Materials. The asphaltic oil used shall be as ordered, but in no case shall oil with a viscosity of less than 250 sec, or more than 600 sec, Lawrence viscosimeter at 100° C (212° F), be used. The sand used shall be clean, sharp and free from adventitious materials of all kinds, but if so ordered may contain not over 5% of clay or loam. It shall contain no stones larger than ½ in in their longest dimensions, or more than 30% passing a 50-mesh sieve.

"Finishing and Acceptance. If at any time before the acceptance of the work any soft or imperfect places develop, the material at these places shall be removed and replaced with new material and rolled until thoroly compacted and until the joints between the new and old work become invisible. Any inequalities in the surface shall be removed by scraping with a road machine, or other suitable scraper. After the surface has been completed to the satisfaction of the engineer, and before the acceptance of the work, a light covering of sand shall be spread evenly over the surface. The surface of the road when completed shall have a crown of ½ in to the ft.

"Climatic and Weather Conditions. No bituminous work shall be done during rainy weather, nor when the weather conditions as to temperature or otherwise are unfavorable for obtaining satisfactory results."

9. Construction Cost Data

The cost of constructing thin bituminous surfaces on broken stone and gravel roads varies from 2 to 10 cents per sq yd. The examples cited give average data covering the details of construction.

Philadelphia (24c). Table I gives the cost of labor and materials used from 1913 to 1916 in the construction of bituminous surfaces with refined tars and asphalt cut-back. Table II gives the detailed costs of construction and retreatments in 1916.

Table I

Labor and Material	Unit Costs			
	1916	1915	1914	1913
Torpedo gravel, per 2000 lb, delivered on the road	$2.10	$2.03	$2.14	$2.50
Trap rock chips, per 2000 lb, delivered on the road	2.02	1.94	2.30	2.30
Tarvia A, per gallon applied	0.085	0.085	0.085	0.085
Tarvia B, per gallon applied	0.07	0.0692	0.07	0.07
Ugite hot, per gallon applied	0.08	0.08	0.09	0.09
Ugite cold, per gallon applied	0.064	0.06	0.08	0.08
Asphalt cut-back, per gallon applied	0.1403	0.0791	0.117	0.12
Asphalt, 150 penetration, per gallon applied	0.0795	0.0791	.....	.....
Asphaltic road oil, per gallon applied	0.0588	0.0484	0.0523	.....
Laborers, per 8 hr day	2.00	2.00	2.00	2.00
Foremen, per 8 hr day	4.00	4.00	4.00	4.00
Asst. foreman, per 8 hr day	3.00	3.00	3.00	3.00
Teams, per 8 hr day	4.80	4.48	4.75	5.20

Average labor cost, per sq yd, for hand and machine sweeping, chipping and clean-up during 1915 .... $0.0105
Average labor cost, per sq yd, for hand and machine sweeping, chipping and clean-up during 1916 .... 0.0114

Table II

*Hot application. †Cold application.

"**Asphaltic Oil Surface on Gravel Road, Cairo, Ill.** (46). The following figures do not include contractor's profit or overhead expenses. Total length of road treated, 8200 ft; total sq yd of road treated, 16 400; condition of old gravel road, fair; kind of bituminous material used, Aztec liquid asphalt; amount of bituminous material used, ⅕ gal per sq yd; amount of torpedo gravel or stone chips, sand, 0.006 tons per sq yd; average length of haul, ⅕ mile; general condition of weather, fair; rate of pay for labor, 15 cents per hr; teams, 40 cents per hr.

Table III.—Itemized Cost of Work

	Total Cost	Cost per Sq Yd
*Superintendence, engineering and inspection	$ 34.20	$0 0021
Bituminous material, 8184 gal at 0 047 cents, f. o. b. siding	384.85	0034
Torpedo gravel and stone chips, 66½ cu yd at 0 59 cents f. o. b. siding	39 25	0024
Heating and applying bituminous material, demurrage, etc	51 85	0032
Spreading torpedo gravel and stone chips, sand	51 66	0031
Sweeping and cleaning old road	[illegible]	00034
Depreciation on equipment	*	*
Freight on equipment	88 20	.0054
Total cost	$656 86	$0.0399

*Indicates paid or furnished by the Ill. State Highway Dept.

"**Asphaltic Oil Surfaces in New Jersey** (39). By light road oil is meant a road oil with an asphaltic base which can be applied at an atmospheric temperature of 21° C (70° F) and by the use of the words heavy oil is meant an asphaltic oil which can be applied only after heating to a temperature of approximately 132° C (270° F). On a road surface which is in good condition and where the travel is light and moderate, light oil is applied and covered with sand. Where the road is in similar condition but is submitted to heavy thru travel or extra-heavy local travel, heavy oil and ½-in stone is spread on the application and rolled. Where the roads are in poor condition, heavy oil and a mixture of 50% of ¾-in stone and 50% of ½-in stone are applied and rolled. Roads badly rutted or containing holes are first patched by either heavy bituminous binder and 1½-in stone or by cold bituminous binder and stone. The county furnishes the oils, the contractor unloads same and applies them, after first cleaning the road. The county then covers them with suitable materials, and in case of stone compacts the covering by rolling. The county's work is done by day labor. The following are unit costs which prevailed during the year 1916, the units given being per square yard of surface treated.

"Light Oil Treatment: 28 lb of sand delivered in wagons at $1 per ton cost $0.014; ½ gal of oil f. o. b. tank car R.R. siding, cost $0.02945; application cost $0.007; cleaning cost $0.0025; and spreading sand cost $0.0020; making a total cost per sq yd of $0.05095.

"Heavy Oil Treatment: 48 lb of broken stone alongside of road, at $2 per ton, cost $0.048; ½ gal of oil f. o. b. tank cars R.R. siding, cost $0.0175; spreading ½ gal of oil cost $0.00875; cleaning road cost $0.0025; spreading stone, $0.0025, and rolling stone, $0.002; making a total cost per sq yd of $0.08125."

Massachusetts Asphaltic Oil Surface. Dean (16c) states that "The average cost during 1910 was a little less than $0.08 per sq yd, and, during 1911, a little more than that price, with labor costing from $1.75 to $2.00 per 8-hr day, and asphaltic oil costing $0.06 per gal delivered in tank cars. The detailed cost on an average road is as follows:

	Per Sq Yd
Cleaning and sweeping	$0.0066
Patching old surface	0.0016
Cost of oil	0.0319
Heating oil	0.0031
Delivering oil	0.0038
Distributing oil	0.0029
Furnishing sand beside road	0.0165
Spreading sand	0.0073
Watering	0.0012
Rolling	0.0002
Supervision	0.0025
Total	$0.0766

"The road mentioned was treated with ½ gal of heavy asphaltic oil in two ¼-gal applications. The average haul was 2 miles for the oil and 2½ miles for the sand. No allowance is made in the foregoing detailed statement for rental or depreciation of machinery, or for profits to contractor, the work being done by labor force account."

Table IV.—Cost of Asphaltic Oil Treatments at Portland, Maine, in 1915 (20)

Street	Sq Yd	Cost per Sq Yd	Gal per Sq Yd	Type of Road
Beacon	1 874	$0.0222	0.23	Broken stone
Congress	5 364	0.0365	0.51	Broken stone
Deering's Oaks	12 434	0.0196	0.30	Gravel
Pine	2 230	0.0284	0.36	Gravel
Stevens Ave	8 186	0.0262	0.38	Broken stone
West	2 451	0.0272	0.33	Gravel
Western Promenade	9 958	0.0142	0.19	Broken stone
Woodford	6 396	0.0248	0.30	Broken stone

Massachusetts Sand and Oil Roads Constructed by the Layer Method (43). "Twenty-five and one-half miles have been built by the Commission since 1905. The surface of these roads has cost from 21 to 33 cents per sq yd, the average cost being 26 cents per sq yd. For a road 18 ft wide this would be $2750 a mile, to which should be added the cost of grading, culverts, etc."

England. The cost of surface tarring varies from 1.25 cents per sq yd for crude tar obtained locally in country districts, where wages are low, to 3 and 4 cents where distilled tar is used and prices generally are higher. The average cost of constructing 2 303 000 sq yd of tar surface in Birmingham in 1917 was 2 cents per sq yd.

France. The average cost of tar surface treatments in 1914 was 2 cents per sq yd.

MAINTENANCE

10. Causes of Failure

The causes of failure of bituminous surfaces are numerous. They may be considered from the standpoint of the condition and character of the original surface, the material used, the method of construction, and local conditions.

Condition of Surface. The failure of bituminous surfaces from the standpoint of the character of the original surface is many times due to failure on the part of those in charge to place the surface in satisfactory condition before the application of the bituminous material. Many cases are noted where bituminous materials are applied over a surface in which are found many pot-holes and ruts, or which is dirty, due either to accumulated dust and dirt or to the original method of construction. In many cases a damp condition of the surface or subsurface has resulted in failure.

Effect of Subsurface Moisture on Bituminous Surfaces. Adler (14b) and (14c) states that "All bituminous materials will deteriorate to some degree on exposure to the air and weather. Well-drained macadam road crusts having a complete bituminous seal, have been found to contain a very appreciable amount of moisture during the early spring, drawn undoubtedly from the subgrade and adjacent earth shoulders. This moisture in the body of the road, under freezing temperature, does more damage to bituminous surface films than any other natural agency. As a further illustration of the importance of frost action, it is reported that in extreme Southern States it is possible to maintain bituminous treated gravel roads as a permanent form of construction, in so far of course as this type can be called permanent; while in certain New England States, with careful attention to drainage, it is found impossible to hold the impervious bituminous surface on gravel roads subjected to the heaving and consequent settling of the spring break-up.

"The action of water beneath the surface treatment is perhaps even more destructive than when above the surface. Even a well-drained macadam road, containing the minimum amount of screenings and fine material in its body, and with an unbroken bituminous seal on its surface, will show moisture in the road crust drawn up thru the capillary spaces, during the winter or at the end of any protracted wet spell. A good, live film of bitumen clinging to the surface of the tightly locked stones will withstand the action of this water providing the road itself remains solid. If, however, the film of bitumen is lying on even a thin mat of stone screenings instead of being attached directly to solid stone, and if the situation is further complicated by poor drainage conditions on the road, it will be found almost invariably that moisture will arise thru the body of the road and be held blotter-like, by the fine screenings, which in cold weather will freeze, expand, and lift the bituminous film from the road surface. This results in a breaking of the seal, and frequently in the complete destruction of the surface treatment."

Bituminous Material. From the standpoint of the physical and chemical properties of the material, many instances may be cited in which failure is due to materials not having the proper characteristics for the conditions under which they are employed. The large percentage of volatile con-

stituents contained in certain asphaltic oils has rendered surfaces constructed with them unsatisfactory because of the long period required for these surfaces to set up so that the bituminous material will not track or the carpet thus formed will not creep and form waves and humps. In certain cases the use of light oils on tar or asphalt surfaces has softened the original bituminous surface to such an extent as to render the road or pavement unsatisfactory for use. See Art. 4.

Construction Methods. From the standpoint of construction, failures are due both to the use of too small an amount of the bituminous material and to an excess of material. Improper application, resulting in uneven distribution, is accountable for many failures of bituminous surfaces. A lack of sufficient covering of stone chips or material of a similar character has rendered the surface sticky and mushy. An excess of covering has caused the formation of a mat of varying thickness.

Unsuitability. There are numerous instances where bituminous surfaces have been adopted under conditions which call for the construction of bituminous concrete pavements or even some type of block pavements. A mat type of construction, which has been employed to a considerable extent, has proved inefficacious in cases where the amount of motor-car traffic was not sufficient to iron out satisfactorily the calk holes caused by the horse-drawn vehicle traffic. See Art. 3.

11. Methods and Cost of Maintenance

Patching. Continuous repairing methods are essential in order to keep the surface of the roadway in satisfactory condition and to reduce the annual cost of surface treatments to a minimum. Methods of patching should be employed which will prevent the road metal in patches from being displaced by traffic. For filling small depressions and ruts of ½ in or less in depth, a very adhesive quick setting bituminous material should be painted over the surface and the depressions filled with tamped road metal which will pass over a ½-in screen and is free from dust. Pot-holes, and ruts having a depth greater than ½ in, should be cut out with vertical sides to the full depth of the depression and then filled with tamped bituminous concrete (see Sect. 10), which may be mixed by using either heated road metal and hot bituminous cement or unheated road metal and bituminous cement especially prepared to set up quickly after being mixed with unheated road metal.

Connecticut Practice in Patching Gravel Roads by C. J. Bennett, Highway Commissioner. "Repairs to roads of this character should be made with the same material used for the superficial coat and preferably by mixing the material with the gravel or sand in making patches. In either type of hot or cold treatment, small patches which are only superficial in their depth can be treated by painting the depressions with bituminous material and adding screenings or gravel to cover, but in deeper depressions, the bituminous material should be mixed with the aggregate and placed in the patches. If the patches are of some extent or depth, the edges should be cut back in order to give a shoulder for the patching material to rest against. Great care should be taken to see that too much bituminous material is not added to these patches; otherwise, they will roll or bunch up above the average surface. In other words, the patches should be of the same consistency as the road surface itself and preferably left slightly below the average."

Patching Methods Used in Montclair, N. J. (23). "The patching this year (1915) is done with stone mixed with bituminous cement at a central point and delivered on the street where needed. For cement, H. G. R. No. 1 was used, obtained from the Headley Good Roads Company, costing 6¾ cents per gal, f. o. b. Philadelphia in tank cars. The stone used was trap, ½-in with ¾-in added for deep holes. Fifty

gallons of the binder were mixed by hand with 7000 lb of trap stone; the stone being spread out level, the binder poured on by hand, and the stones then turned over by shovel. Machine mixing would probably be cheaper, and will be used during 1916. In applying the stone thus prepared, the hole is cleaned of dirt and loose material, the prepared stone spread, and rolled. In some cases the depression has worn so large that the patch extends the full width of the paved strip of the roadway, which is generally 18 ft. Including cost of materials and an average haul of 2 miles to the street, this costs about $7 for the amount above described. Fifty-one thousand gallons of binder were used this year in preparing patching material in this way. This material seems to be just about as durable as the clay-bound macadam which it is used to patch, and therefore does not either rise in humps above the pavement as the macadam wears down, or wear more rapidly and produce holes again."

British Practice in Patching Tar Surfaces (49). "To take out pot-holes, ruts, and similar irregularities in the surface, peck round them and remove the worn granite and other material to a depth of 1½ to 2 in to secure an ample key and body to the patch; carefully brush the hole over with hot tar and fill in with previously tarred 1½ to ¼-in graded material, using the greatest care to ram solid. The patch should be so finished that it is not more than ¼ in higher than the adjacent surface of the road, to allow for shrinkage and further consolidation under traffic. If this course is carefully followed the patch quickly becomes level with the surrounding surface. If a patch is finished so that it sets above the surrounding level the fact that it is harder than the road itself causes traffic to bump upon it both ways; excessive wear takes place on both sides as a consequence; other holes form around it, and the road becomes so bumpy as to be almost unrideable. If the patch is finished below the surrounding level, traffic quickly wears down the edges of the road around it, the tar painting breaks away and allows the penetration of water."

Retreatments. The life of a bituminous surface and its economical use depend primarily upon traffic conditions, the method of construction, and the nature of the bituminous material used. With the heavier grades of bituminous materials adaptable for this work, if the road is subjected to a normal traffic for which the method and material are economical and suitable, retreatment is necessary every 1 or 2 years. Under traffic conditions demanding some other type of construction, it may be necessary to retreat the road twice each year, as is done in the case of the Avenue du Bois de Boulogne in Paris. A retreatment can generally be accomplished by using a smaller amount of bituminous material than was used in the first treatment (see Art. 9, Table II). The same care should be taken in preparing the road surface as is used in the original treatment. It is essential, in the case of blankets that bare spots should be painted first and then the entire surface covered with as light an application as practicable. If an amount, sufficient for the formation of the blanket over the bare spots, is applied for the entire surface, an excess of bituminous material will exist over much of the roadway and the usual result will be the formation of a soft, uneven, mobile mat, which will soon be displaced by heavy weight traffic.

Philadelphia Practice in Retreatment of Tar and Cut-Back Asphalt Surfaces. See Art. 9 for amounts of materials used and costs per square yard.

Massachusetts Practice in Retreatment of Tar and Asphaltic Oil Blankets (30c). "For the first treatment is used about ½ gal of oil, with a viscosity of between 40 and 50 sec, Lawrence viscosimeter, at 100° C (212° F), followed in the second season with about ⅜ gal of oil with a viscosity of about 100 sec, and the third season from ⅙ to ¼ gal of similar oil. After that not over ⅙ gal should be needed, and retreatment will probably not be necessary every year. After the second or third year oil with a viscosity up to 200 sec can be used to good advantage."

Maine Practice in Retreatment of Tar Surfaces on Gravel Roads. Sargent (50) cites as an example a gravel road which carries for 4 months in the year an average traffic of over 1200 vehicles per day and on Sundays and holidays a traffic running from 3000 to 3500. Since 1915 this road has been maintained by early patching and dragging, and shaping with gravel. This work has been started as soon as the snow has

left the ground and the surface of the road began to soften up, which usually was about the middle of April. Most of the surface treated gravel breaks up after freezing and thawing begins in the fall. After the snow leaves in the spring the tar crust breaks up into scales of perhaps ¼ to ½ in in thickness and in sections having a surface area anywhere from 1 sq in to 1 sq ft.

"In 1915 the first retreatment with Tarvia-B was made in June, using 0.3 gal per sq yd. About the middle of August, a second application was made, using 0.2 gal per sq yd. In 1916 and 1917, about May 20, or as soon thereafter as the weather was warm and the roadway dry, the surface was prepared by sweeping with a horse sweeper and hand brooms to remove any loose particles of dirt or dust. The tar was applied at the rate of 0.4 gal per sq yd of surface. The surface treatment was 16 ft wide, the same width as the gravel surface, the application being made with automobile trucks fitted with spray bars covering 8 ft. The tar surface was covered with stone using about 1 cu yd to 100 sq yd.

"If there are any pockets of dust or soft places in the gravel, the tar surface will break up, and such places have to be immediately attended to by the patrolman. Patching is done in two ways, either by mixing sand and Tarvia-B together in the proportion of 1 gal of tar to 1 cu ft of sand and putting that in the hole and then patting it down with a shovel, or, if the broken place is found soon enough, the patrolman simply gives it a little brush of tar with an old broom. Sometimes a light sprinkle of sand is thrown over the tar. The edges of the tar treatment are inclined to crumble off as a result of traffic turning out over them and a good deal of the patrolman's time is taken up with patching the edges with the mixture of Tarvia-B and sand.

"The cost of maintenance on the above section was as follows:

	1915	1916	1917
Patrolman's wages	$ 209.81	$ 329.16	$ 417.53
Extra help	91.28	624.57	450.59
Material	1036.99	1309.49	1250.68
	$1338.08	$2263.22	$2118.80
Inspection	25.10	182.03	175.00
Total cost	$1363.18	$2445.25	$2293.80
Cost per square yard	$0.053	$0.095	$0.08"

Repair and Removal of Bituminous Surfaces. In the case of thin superficial treatments with refined coal tars, water-gas tars and cut-back asphalts, retreatments may be employed for many years, if the work is properly done as in the case of the bituminous surface treatments in Philadelphia referred to in Art. 10. European practice gives instances where tar retreatments have been successful for over 10 years. When carpets of over ½ in in thickness are employed, there is a marked tendency under horse-drawn vehicle traffic for the surface to be displaced by the blows of horses' hoofs, and, when the roadway is subject to heavy weight traffic, waves and other irregularities of the surface soon appear. While it is practicable in some cases to smooth out uneven carpets by the use of planers and other special devices, it is usually impracticable to maintain carpets, under the traffic noted, in satisfactory condition for more than 1 to 5 years. When the carpet is in such condition that retreatments and repair methods are inefficient, the removal of the bituminous surface is the only economical solution. This may be accomplished by scarifying or by the use of picks and shovels.

Mass. Highway Comm. Practice in Reconstruction of Bituminous Surfaces, as described by Farrington (30c), is as follows: "Any water-bound macadam or gravel surface maintained with oil or tar will have to be reconstructed or reshaped occasionally. With macadam, if not to be reconstructed, the usual custom is to break up the surface, remove the tar or oil if necessary and reshape. The roller picks, or a scarifier, or both, are used for breaking up, followed by a thoro harrowing, preferably using both the

straight tooth and curved spring-tooth harrows. The former completes the breaking up and the latter brings the coarser particles of road metal to the top. Usually some new stone is added and it may be necessary to use some sand or other material, as the voids must be filled to near the surface; but ordinarily there will be sufficient fine material in the old stone. To obtain good results there must be no sand or other fine material on the surface and the stone on top must be clean, but the voids must be filled so the bituminous material will not penetrate far below the surface. This is necessary, not only to avoid the use of an excessive amount of bituminous material and hence increase the cost, but also because with the grade used any surplus bituminous material in the voids will eventually work up and cause the surface to roll.

"About ½ gal of oil per sq yd should be put on in two applications with a covering of sand or other grit after each application. Before applying the bituminous material the road should be rolled with a steam roller, and much of the success of this work depends on a thoro rolling. A final rolling after the bituminous material has been applied and covered is advisable.

"The methods used in forming oil or tar blankets on gravel and the methods of maintenance are similar to those for broken stone, except that for the first application it is essential that the oil or tar used be light enough to penetrate somewhat and thus form a thoro bond with the gravel. In reshaping gravel it is necessary to loosen the surface only enough to shape with a road machine unless there is a thick blanket of oil or tar, in which case this must be removed or thoroly broken up and mixed with the gravel by harrowing."

Connecticut Practice in Reconstruction of Bituminous Carpets on Gravel Roads, by C. J. Bennett, Highway Commissioner. "Reconstruction of roads treated with a superficial bituminous material is a somewhat difficult matter. If much of the material remains upon the surface of the road, it should be entirely removed. In fact, the necessity for reconstruction generally arises from the unevenness of the surface due to the fact that some of the bituminous surface has been worn out or has bunched up into rolls giving the well-known washboard effect. There are several methods of reconstruction, the most radical of which consists in removing the bituminous material, scarifying and resurfacing the road. Good results may sometimes be obtained by treating the rolled bituminous carpet with a light application of non-asphaltic oil which will tend to soften up the surface. After the asphaltic oil has been applied for a short length of time, a planer or heavy road drag may be dragged over the road back and forth until the surface becomes even, after which it may be partially covered with new fine gravel or stone chips, and the patching and maintenance continued as outlined above."

Connecticut Hone or Planer. Ulrich (56) states that "The zigzag hone is constructed of heavy oak plank reinforced by metal straps and ½-in metal cutting edges, which are slotted to give necessary adjustments. The zigzag feature moves the material out from the high points, and distributes it in the hollows. The rear blade is a solid distributing blade, and a hole is cut in the side member, just in front of this blade, to allow any excess material to pass out to the side of the road and not pile up in front of the blade. This hone is about 8 ft wide and 10 ft long. Should the surface prove too hard to yield to this hone, a modification of the Hedley planer is employed. This plane has been built of heavier channels, with an improved method of holding the teeth which allows a quick adjustment whenever necessary. The spacing of the channels carrying the teeth has been changed, and a hole cut in the side channel, just forward of the rear distributing blade, to allow excess material to pass out, as is the case in the zigzag hone."

Asphaltic Oil Carpets Smoothed with Scarifier and Scraper in Riverside, Cal. (29). "Experiments were made with harrows, or toothed scarifiers, but altho they gave a measure of success the teeth were found to wear excessively and did not permit of a sufficiently flexible control. Further experiment applying the rotary disk idea met with greater success, and for several years now scarifiers have been in service with which roughened pavements have been effectively restored to a high degree of smoothness. The disks are 18 in in diameter and are spaced 1 in apart by cast-iron spreaders. The sets are so adjusted that the outer disk on each set is offset 1 in from the track of the near disk on the preceding set. The axles of the disk sets are not quite parallel to the main axles of the scarifier, as it has been found that a slight in-

clination aids in turning the loosened material out of the cuts. This inclination is usually such that with 30 disks all spaced 1 in apart the actual effective cutting width is 28 in. This inclination is kept constant for all disk sets and can be changed by adjusting a pair of bolts on the frame. The entire set of disks is shifted right or left, lifted or depressed, by hand wheels on the operator's platform.

"The method is to loosen the surface of the high spots with the scarifier and follow with a road grader, which cleanly scrapes off the loosened material and leaves it in convenient shape to be gathered and hauled to the yard. These scrapings are kept free from foreign material by sweeping the pavement with a rotary brush just before scarifying it. After having cut the surface down to grade, the depressions are swept by hand, painted with heavy base crude petroleum and the requisite amount of the loose material or scrapings is filled in and tamped. Depressions so filled have given satisfactory service for 5 years. It is not, however, intended to use this method where actual patching of the surface is required; only depressions less than 1 in in depth are treated in this way.

"Scarifying and scraping are done only in the afternoons during warm weather. The scrapings after being delivered in a winrow along the gutter by the road grader, are left until the following morning, when they can be handled more conveniently than when the temperature is high. The usual road crew on this work consists of 2 4-horse scarifiers and 1 road grader, each with 1 driver and 1 operator. Where the surface is rough, progress is at the rate of about ½ mile of 60-ft street per day; but up to 1 mile per day has been made where the roughening had developed to a lesser degree."

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SECTION 15

BITUMINOUS MACADAM PAVEMENTS

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GENERAL DATA

1. Description and Definitions

Definition. A Bituminous Macadam Pavement is one having a wearing course of macadam with the interstices filled by penetration methods with a bituminous binder. Adopted in 1915 by the Spec. Com. Mat. Road Cons., Am. Soc. C. E.

Historical Development of the Derivation of Bituminous Macadam. In America, prior to the general use of penetration methods in the construction of bituminous pavements, the term bituminous macadam was widely used to describe bituminous pavements constructed by the mixing method. In 1902, Fred J. Warren, in discussing Bitulithic pavements, made the following statement (55): "The name bituminous macadam may be considered too nearly descriptive to be controlled by any one interest or to be a trade name but, so far as the writer is aware, it was coined for use in connection with letters patent governing methods and proportions of mixing various size mineral ingredients with bitumen, for paving purposes, and in noting the development the writer will confine himself to the experiences of Warren Brothers Co., who control these patents."

When bituminous pavements constructed by penetration methods were used in the United States, the term, bituminous macadam, was applied to them. The term then became indefinite as it was used with reference to two types of bituminous pavements which differed fundamentally in their methods of construction. The general misinterpretation of specifications, articles in the technical press and cost data resulted in a reconsideration of definitions of bituminous pavements in the construction of which broken stone was used.

The Assn. Standardizing Paving Specifications in 1912 adopted a specification for a Bituminous Macadam Pavement, the description of the wearing course being as follows: "Upon the foundation shall be evenly spread stone, which shall pass a 2½-in revolving screen and be retained upon a 1-in revolving screen, to a finished depth of 2½ in. This course shall be dry-rolled with a road roller weighing not less than 10 tons until the individual fragments have keyed together the surface, while even and conforming to the required crown, being left open or porous in order to allow the penetration of the hot bituminous binder." In its Report, the Committee, recommending the above specifications, stated that "In order to avoid confusion we ask that this type of road be known as bituminous macadam pavement, and would suggest that pavements laid by the mixing method be referred to as bituminous concrete."

The Spec. Com. Mat. Road Cons., Am. Soc. C. E., in its 1913 and subsequent reports restricted the use of bituminous macadam to bituminous pavements constructed by penetration methods.

The Am. Soc. Mun. Imp. in 1914 adopted a specification for a bituminous pavement constructed by a penetration method, designating it a Bituminous Macadam Pavement; and in 1915 adopted a specification for a bituminous pavement having a wearing course composed of one product of a stone crushing plant mixed with bituminous cement, designating it a Bituminous Concrete Pavement.

U. S. O. P. R. Prior to 1916 the U. S. O. P. R., in its publications, used the phrases, "bituminous macadam by the penetration method," and, "bituminous macadam by the mixing method." In 1916 it adopted the terms "bituminous macadam" and "bituminous gravel" to designate bituminous pavements constructed by penetration methods using respectively broken stone and gravel for the road metal, and the term "bituminous concrete" to designate bituminous pavements constructed by the mixing method in which the mineral aggregate was composed of broken stone, broken slag, gravel, or similar material, either alone or in combination with other non-bituminous materials.

Status in 1917 (35). "The terms 'bituminous macadam' and 'bituminous concrete' are now generally recognized as the proper designations for the two general classes of pavements of relatively coarse mineral aggregate bound with bituminous material. By the usage of those most conversant with road-building terminology the former is applied to bituminous pavements built by the penetration method and the latter to bituminous pavements built by the mixing method. According to the present understanding of the terms in question, a bituminous pavement built by the mixing method is not a macadam road at all, but a concrete pavement. It should, therefore, be designated as such, with the term 'bituminous' to distingush it from a cement-concrete pavement. It is gratifying to note that the Office of Public Roads has seen fit to conform to the usage *Good Roads* has so long advocated and that has been so generally followed elsewhere. There would seem to be no good reason for using any different nomenclature at present and it is to be hoped that the example of the Office of Public Roads will be followed by writers who still cling to the older and more clumsy forms."

2. Historical Development

History of Bituminous Macadam Pavements in France. Lieut. H. W. Halleck, U. S. Engineer Corps, stated in 1840 (30a) that "for 30 to 50 years, mineral tar, in combination with sand and calcareous matter, has been used in Bordeaux and its vicinity for roads, pavements, floors and the roofing of houses. It was first used, with sand only, in the repair of roads near Bayonne, and being found to answer this purpose, it came afterward to be employed by builders, in its combined form, in preference even to slate and stone; and many houses at Bordeaux are now roofed with it. Regarding the use of bitumen on macadam roads, Lieut. Halleck described the now so-called penetration method as follows:

"'The soil is first removed to a depth of about 5 in, according to the thickness to be given to the road covering, and the earth well rammed; to make it still more firm, small broken stones, about 1 cu in in size, may be driven in. A layer, about 4 in thick of broken stone from ¾ to 1 in in diameter is spread over and smoothed off so

as to give the surface a slight curvature. Over this is poured a very hot and liquid mixture, of ⅓ coal tar, ⅓ pulverized asphaltic stone, of an inferior quality, and ⅓ fine sand. A sufficient quantity should be put on to penetrate all the crevasses of the stone and form a solid mass. After this has become cold, a layer of good bituminous mastic, about 1 in thick is applied, and, while still hot, is covered with a layer of broken stones about 1½ in in diameter, placed close together, but without touching and pressed into the mastic by an iron roller. The thickness of this covering may be varied, according to the wear and tear it will have to resist.' "

History of Bituminous Macadam Pavements in England. In 1820 a bituminous macadam pavement, constructed with a tar cement, was laid in London. Church (24) states that "The principle of constructing a broken stone road, having a binder composed of soft pitch and sand, was the subject of a patent 4 years earlier than the invention of creosoting timber in 1838, with which date the active beginning of the industry of tar distilling is usually associated. In fact, John Henry Cassell secured his patent in 1834, only 22 years after gas was first made in London, so that instead of being one of the latest developments in the industry, this method, so far as it relates to the use of coal tar pitch and sand, is really one of the oldest." In 1901, John A. Brodie constructed the first section of Pitchmac on Princes Ave., Liverpool.

Development in the United States. The penetration method of constructing bituminous pavements has been used extensively in the United States since 1908 in building roads and residential streets, due to its low first cost and the rapidity with which it may be constructed with proper plant equipment and under favorable climatic conditions. The fundamental reasons for the adoption of bituminous macadam pavements by many municipal engineers are given as follows in the introduction of the 1912 Rep. of the Com. Macadam Paving Specifications, Assn. Standardizing Paving Specifications.

"Members of this Committee unanimously agree that water-bound macadam pavement is not a proper permanent pavement to lay, for the following reasons: (1) Since the introduction of the automobile this pavement will not withstand automobile traffic; (2) that bituminous macadam can be laid to withstand this traffic at a cost equal to water-bound macadam when the maintenance is taken into consideration; (3) that a water-bound macadam pavement on residential streets, unless properly sprinkled either with oil or water, is an objectionable pavement on account of dust for the abutting property owners, and unless a great deal of care is taken in sprinkling water, the road is injured to a large extent, and if oil is used it can better be done by original construction using a penetration method."

3. Characteristics

Advantages. The advantages incident to the construction of bituminous surfaces on broken stone and gravel roads enumerated in Sect. 14 are also characteristic of bituminous macadam and bituminous gravel pavements. Many bituminous pavements constructed by penetration methods possess the following advantages: Suitability for horse-drawn as well as motor-car travel; freedom from dust when in exposed localities; low external and internal wear of road metal; low cost of cleaning, watering, and in many cases, of repairs; imperviousness and a certain degree of density of the wearing course; noiselessness and low traction with certain types of bituminous materials; very good sanitary qualities; low cost of plant equipment for methods of construction commonly used in the United States.

Disadvantages. Among the disadvantages attendant upon the use of bituminous macadam and gravel pavements are the following: Increase in cost over bituminous surfaces on broken stone and gravel roads; slipperi-

ness when some bituminous binders are used on certain grades; dependence upon climatic conditions in order to carry on construction properly; variability in results and lack of uniformity in composition of wearing course secured, due to uneven penetration and uneven distribution of the bituminous binder, and segregation of road metal; unstable wearing course due to lack of compaction of the road metal.

Conclusions of Ill. Highway Comm. (40a). "Experience indicates that this form of construction is adapted to moderate traffic roads, that is, where there is no large amount of extra heavy hauling. Where the traffic is composed of automobiles and farm loads not to exceed 2 tons, this form of construction will prove satisfactory, altho possibly not as durable as either concrete or brick. Where traffic consists of heavier loads, wholesale trucks, heavy coal hauling, and loads reaching to 5 and 6 tons, it is believed this form of construction is not at all suitable. It presents a pleasing appearance and is well adapted to horse-drawn traffic as well as automobile traffic, but requires close attention for maintenance, and there is some evidence that during warm weather when the bitumen is least stable there is a tendency for the surface to creep and undulations develop. Bituminous macadam is of doubtful value on those sections of roads so situated that considerable quantities of mud will be tracked on them from adjoining roads."

Conclusions Based on N. Y. State Highway Comm. Practice by Breed (21). "Bituminous macadams in general are not wholly satisfactory. When built on hills it is not safe to apply a flush coat; consequently the road is far from being waterproof when first constructed. This defect is remedied by the traffic, which grinds up the stone and forces it into the voids, but the lack of uniformity in the finished results of these roads has many times been discouraging. In building the bituminius macadam it is impossible to get full consolidation, and consolidation by traffic afterwards makes this type ridgy. As yet the tendency of this type of pavement to creep under traffic has not been corrected. Wonderful examples where this condition has almost been eliminated have occurred, but under similar conditions one road may be a success in this respect and another a near-failure. Oftentimes roads built by the same contractor, under the supervision of the same engineers, using the same care and inspection of materials, will stand well in one case, and in another lose shape and disintegrate in spots within a short time. Among the disadvantages of this type of construction are that it is slippery, has a fairly high cost of maintenance, $493 per mile (16 ft wide) during 1916 and $412 during 1917, and that during repairs the road must be closed to motorists lest it cover their cars with oil and tar. These roads have the advantage of being dustless and easily repaired when street openings are made or when depressions occur."

4. Drainage and Foundations

In Sect. 8, Arts. 10 to 21, inc., the characteristics and suitability of all methods of surface and sub-surface drainage, and all types of foundations are discussed.

Broken Stone Foundations. Usually bituminous macadam pavements are constructed on broken stone foundations similar to the types described in Art. 10 in connection with methods of construction and in the various specifications contained in Art. 11.

Ohio State Highway Dept. Practice by Sharp (46). "On account of the greatly increased loads now (1917) being carried over improved roads, it is thought best that the foundation course be 5 in at the center and 4 in at the outsides. If a thicker course than this is required, it will be necessary to lay the foundation in two courses since it is not practicable to attempt to fill a course of greater thickness than this. Rolling should begin with the outside driver covering equal parts of the metal and shoulder. When the shoulders and sides of the metal are thoroly rolled, the rolling should progress gradually toward the center from each side until the entire course has been thoroly keyed and the interstices of the metal reduced to a minimum and all settlement has ceased. All low places developed during the rolling should be loosened, reshaped with suitable material and again consolidated by rolling. During the process of rolling one experienced in this kind of work can by careful attention rearrange the metal in the sur-

face to the extent of eliminating much of the unevenness and wavy surface conditions. Screenings that pass a ¾-in opening and not more than 40% passing a ¼-in opening, should be applied during the finishing process of dry rolling in such an amount as will completely fill the interstices. The screenings should not under any circumstances be dumped upon the surface of the stone, but should be cast thinly with a spreading motion of the shovel from piles at the roadside. If men are not experienced in the knack of whipping the screenings from the end of the shovels, during the process of filling, it is likely that the surface will be bridged in places by the screenings and complete filling not secured. It is very important that this be guarded against and the work be done under supervision of some one with an understanding of the proper method of carrying on this part of the work. The rolling should continue while the screenings are being spread so that the jarring effect of the roller will aid in settling them to the bottom. The roller should pass over the entire surface of the road after each application of screenings. In all probability, as the course is being compacted, it will be necessary to sweep the surface with a rattan or steel broom in order to effect a uniform distribution of the screenings and completely fill all voids. No excess of screenings should be used before applying water. Sufficient water should be applied to insure a dense surface and completely fill all interstices, the rolling to continue and screenings added until the metal ceases to sink under or move in front of the roller."

Cement-Concrete Foundations. In cases where traffic conditions require rigid foundations or where materials satisfactory for cement-concrete may be secured at a much lower cost than broken stone, cement-concrete foundations have been used and have been found to be satisfactory and economical. The more general use of cement-concrete foundations is advisable on trunk or other highways where traffic is liable to increase rapidly, both in amount and weight. When it is necessary to construct a more durable type of wearing course than bituminous macadam, the cement-concrete foundation previously constructed proves a valuable asset and allows reconstruction to be accomplished economically provided that proper foresight was exercised in placing the surface of the cement-concrete foundation at such an elevation as will permit the construction of other forms of pavements thereon. This remark applies particularly to curbed roadways in municipalities.

For a discussion of the relative advantages and cost of using broken stone and cement-concrete foundations see Art. 10, Method E and (22).

Conclusions of Third Int. Road Cong., London, 1913 (52). "Confirming the conclusions adopted in 1910 by the Second Congress, which called attention to the advantages of a dry foundation and a sound subsoil, the Congress especially insists upon the great importance of efficient foundations in the case of road crusts bound with bituminous binders for the following reasons:

1. The road crust being expensive, it is important to give it a base which will increase its life.

2. As the weight, speed and intensity of the traffic continually tend to increase on roads considered worthy of such a crust, it is best to provide a foundation which has been so constructed as to secure for the crust the best possible conditions of resistance to wear.

Conclusions of Spec. Com. Mat. Road Cons., Am. Soc. C. E. (16e). "The use of any form of a bituminous pavement or bituminous surface does not preclude the necessity for the construction of a well-drained, thoroly compacted, and adequate foundation. In fact, such improvement of the highway frequently attracts heavier traffic, and thus increases the stresses on the subgrade."

Conclusions of Ill. Highway Comm. (40a). "The results of the experience so far gained seem to show the necessity in this form of construction for as stable a foundation course as possible, and that probably the best method would be to lay the first course of the road as water-bound macadam, applying the bituminous top about 3 in thick the following season when the foundation course had become thoroly well compacted."

MATERIALS

5. Non-Bituminous Materials

Physical Qualities. In selecting and specifying rock and slag to be used in the construction of bituminous macadam pavements, toughness, resistance to abrasion, shape, and character and cleanliness of surface should be carefully considered.

Toughness and Resistance to Abrasion. See Sect. 11, Arts. 4 and 5. The weight to be given to these properties depends primarily upon the traffic to which the pavement will be subjected and the details of the method of construction adopted. For example, for many highways serving as feeders to state trunk routes, a rock having a toughness of not less than 6 and an abrasion loss of not more than 6% would prove economical and satisfactory; but if used on state trunk highways subjected to horse-drawn or motor-trucks, rock having a toughness of not less than 13 and an abrasion loss of not more than 3.5% should be employed. In cases where rock with suitable toughness and wearing quality is not locally available, satisfactory results may be obtained by importing the broken stone for the surface of the pavement and using local rock for the lower part of the crust.

Shape. In order that road metal should interlock during compaction and thus provide a stable wearing course, a proper angularity is an important prerequisite. The provision, often found in specifications, that broken stone should be cubical in shape is intended to cover this desirable quality of road metal. Cubes of rock or slag are not obtainable in practice, but the road metal meeting such a specification should not contain over 5% of particles having small acute angles, nor should the product contain slivers. Road metal with long acute angles and slivers is liable to rapidly fracture and crush under truck traffic.

Character of Surface. Road metal which has a rough or coarse grain or pitted surface is preferable to material with smooth or glassy surfaces as the bituminous cement adheres more satisfactorily to the former than to the latter.

Cleanliness is an essential quality of road metal for the wearing course of bituminous macadam pavements. Many failures have occurred from the use of dirty stone. It is difficult and usually impossible to secure a good adhesion of the bituminous cement to road metal which is not clean.

The Sizes of broken stone and slag used in bituminous macadam pavements vary primarily with the method of construction employed and the qualities of toughness and resistance to wear which the road metal possesses. As explained in Art. 10, covering methods of construction, and as illustrated by specifications contained in Arts. 6 and 11, the products used for wearing courses vary from one having road metal passing 1¼-in and retained on a ½-in screen to one in which the particles pass a 4½-in and are retained on a 3-in screen. The proper kind and size of material to be used as a filler will depend primarily upon the product used for the body of the wearing courses. For filler used in different methods, see Arts. 10 and 11.

From the standpoint of physical qualities, a safe rule is to increase the size of road metal as the toughness decreases or the loss by abrasion increases.

In using products, the particles of which are about the same size, special care must be taken in filling the voids of the wearing course in order that no rocking of the stone occurs. With hard, tough rocks there is more danger

of failure from this cause than when rocks or slags low in toughness and with a high loss on abrasion are used. The use of the trap rock product, the analysis of which follows, was the principal cause of one failure: Passing 1½-in screen, 37.5%; passing 1¼-in screen, 59.5%; passing 1-in screen, and retained on ½-in screen, 3.0%.

Massachusetts Practice Relative to Sizes and Qualities of Stone (31). "The size of stone in the top course is regarded as a matter of vital importance in the construction of a road by the penetration method. The Mass. Highway Comm. employs stone ranging from 1½ to 2½ in in size. The large stone, it has been found, binds together more firmly than smaller stone and consequently is subject to less wear from the grinding of one fragment against another in the body of the pavement due to the passage of vehicles over the road surface. Small-sized stone tends to loosen quickly under this grinding action, and if the bituminous binder loses its life and is not speedily renewed the road quickly goes to pieces. With stone of large size no such result may be expected. It is true that with the larger stone the voids are greater and consequently a larger amount of bituminous material must be used to fill them, the excess being generally about ⅜ gal per in depth of top course for the large stone type of construction. Thus a small stone pavement with tar as a binder and a 2-in top course would cost about 6 cents less a square yard than the large stone type of pavement. In spite of this slight increase in cost, the use of the large stone is believed to be amply justified. With small stone it is practically impossible to secure any great depth of penetration with a single application of bituminous material. It becomes necessary, therefore, if small size stone is used, to build the top course in several layers and apply the binder to each, obviously a more costly procedure than the distribution of the binder in a single operation as is feasible when large stone is used.

"As to the quality of the stone in the top course, this depends to a large extent upon the character of the traffic to be handled. For very heavy teaming the Mass. Comm. believes that the best results can be secured with trap rock and a high grade asphalt. With a tar binder, instead of asphalt, a softer grade of rock is permissible, for the tars deteriorate more quickly than do the asphalts. Asphalts are preferred because of their greater cementing value and their higher resistance to disintegration by moisture."

Ill. Highway Comm. Conclusions Relative to Sizes and Quality of Stone (40a). "Durable material in the bituminous top should be used, and where, under the conditions that exist in Illinois, limestone alone is available, the material used for filling the voids and dressing the surface of the bituminous layers as they are applied, should be of washed gravel and torpedo sand. The particles of the gravel are made up for the most part of silicious material, which is the hardest material available, but where the rock of which the road is made is tough and hard, then rock chips could be substituted. The size of stone in the bituminous layer should range from 2½ to ¾ in where limestone is used. When trap rock or other equally hard material is available, stone should not exceed 2 in in size; the chips for filling the stone not to exceed ¾ in and the grit for the top dressing not to exceed ¼ in, and all of the materials to be free from dust."

Conclusions on Sizes of Stone for Filling Voids by Hubbard (38a). "Immediately after application of the bituminous material a light layer of clean, dry, broken stone, which will pass a ⅝-in but be retained upon a ¼-in screen, should be evenly spread over the road and at once rolled into the surface voids. Frequently a larger size of broken stone is used for this purpose, that is, stone as large as ¾-in diameter. This is bad practice for the reason that if the top course has been properly constructed and rolled the surface voids are not sufficiently large to accommodate ¾-in stone. Under the action of the roller they will therefore either be crushed or if of very hard rock will project into the finished surface. In the first case so much dust is produced as to prevent proper penetration and adhesion of the seal coat of bituminous material which is afterwards applied. In the second case the stone is of such size as to be more or less readily caught and pried out by traffic, especially horse-drawn traffic. On the other hand, if the stone above recommended is used, the surface voids of the properly compacted top course may be evenly filled and a minimum amount of crushing will be produced by the roller. In addition, satisfactory surface consolidation is more readily obtained as there are no scattered high points for the roller to pass over and the weight of the roller is thus more evenly distributed over the entire surface."

6. Specifications for Non-Bituminous Materials

The most satisfactory form of specifications covering sizes of broken stone is that recommended by Com. D-4, Standard Tests for Road Materials, Am. Soc. Test. Mat. and the Spec. Com. Mat. Road Cons., Am. Soc. C. E. (see Art 7, Sect. 11).

The Form of Specification for broken stone for bituminous macadam, as adopted at the first conference of State Highway Testing Engineers and Chemists held at the U. S. O. P. R. in Feb., 1917 (53 b) was as follows:

"**General.** The broken stone shall consist of angular fragments of (insert types of allowable), of uniform quality thruout, free from thin or elongated pieces, soft or disintegrated stone, dirt, or other objectionable matter occurring either free or as a coating on the stone.

"**Physical Properties.** The stone shall meet the following requirements:

Percent of wear..........................not more than..........
(or French coefficient).....................not less than..........
*Toughness..............................not less than..........
*Hardness...............................not less than..........
*Absorption.............................not more than..........

"**Chips or No. . . . Stone.** That portion of the product of the crusher which, when tested by means of laboratory screens, will meet the following requirements:

Passing..........inch screen................................100%.
Total passing..........inch screen............% to............%.
Retained on..........inch screen............................100%.

"**Top Course or No. . . . Stone.** That portion of the product of the crusher which, when tested by means of laboratory screens, will meet the following requirements:

Passing..........inch screen................................100%.
Total passing..........inch screen.............% to ....%.
Retained on..........inch screen............................100%.

"**Bottom Course or No. . . . Stone.** That portion of the product of the crusher which, when tested by means of laboratory screens, will meet the following requirement:

Passing..........inch screen................................100%.
Total passing..........inch screen.............% to...........%.
Retained on..........inch screen............................100%."

Am. Soc. Mun. Imp. 1917 Specifications for Broken Stone are as follows:

"**Quality of Broken Stone.** All broken stone shall be clean, rough surfaced and sharp angled, of compact texture and uniform grain.

"**Tests for Broken Stone.** The broken stone shall be subjected to abrasion tests and toughness tests conducted by the Engineer in accordance with methods adopted by the Am. Soc. Test. Mat., Aug. 15, 1908. The broken stone used for the construction of the first and second courses shall show a French coefficient of wear of not less than 7.0 and its toughness shall be not less than 6.0. The broken stone used for the construction of the third course and for the first and second applications of No. 1 broken stone shall show a French coefficient of wear of not less than 11.0 and its toughness shall not be less than 13.0."

Sizes of Broken Stone. For specifications covering the sizes to which reference is made in the specifications for construction contained in Art. 11, see Art. 7, Sect. 11.

U. S. O. P. R. 1918 Specifications for Broken Stone are as follows:

"**General.** The broken stone shall consist of angular fragments of rock excluding schist, shale and slate, of uniform quality thruout, free from thin or elongated pieces, soft or disintegrated stone, dirt or other objectionable matter occurring either free or as a coating on the stone.

"**Physical Properties.** The stone shall meet the following requirements: French coefficient of wear, not less than 7.

"**Chips.** That portion of the product of the crusher which, when tested by means of laboratory screens, will meet the following requirements:

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*Tests recommended by the conference which it may be desirable to omit in some instances.

	Percent
Passing 1-in screen, not less than	95
Retained on ¼-in screen, not less than	85

"Coarse Stone. That portion of the product of the crusher which, when tested by means of laboratory screens, will meet the following requirements:

	Percent
Passing 2-in screen, not less than	95
Total passing 1½-in screen	25 to 75
Retained on 1-in screen, not less than	85

"Methods of Testing. Tests of the physical properties of the rock and of the sizes of broken stone products shall be made in accordance with the following methods:

1. French Coefficient of Wear: U. S. Dept. Agr. Bul. 347, p. 5.
2. Size: U. S. Dept. Agr. Bul. 555, p. 32.

"Notes: This specification covers stone to be used in the construction of a bituminous broken stone wearing course in which the bituminous material is applied by the penetration method. The maximum size of 2 in specified for the wearing course is on the basis of a course 2½ to 3 in in thickness after consolidation. The chips should be used to fill the surface voids after the first application of bituminous material has been made and also as a cover for the second application or seal coat."

Ohio State Highway Dept. Specifications for Road Metal are as follows (46):

"Limestone for Foundation Course. The broken stone shall be clean, sound, durable and of uniform quality. It shall contain not less than 55% of calcium carbonate except in the case of a dolomitic limestone, when the sum of the percentage of calcium carbonate and magnesium carbonate shall be not less than 60%. The stone shall show in the abrasion test a loss of not more than 12%, a factor of hardness of not less than 10 and a toughness of not less than 4.

"Slag for Foundation Course. The slag shall be clean, sound, durable and of uniform quality and shall contain not less than 30% of silica and not more than 45% of calcium oxide and not more than 1.5% of sulphur. The slag shall show in the abrasion test a loss of not more than 12%, a factor of hardness of not less than 14 and a toughness of not less than 5.

"Sandstone for Foundation Course. The sandstone shall be clean, sound and durable and of uniform quality. The stone shall show in the abrasion test a loss of not more than 25% and a toughness of not less than 3.

"Limestone for Wearing Course. The stone shall be clean, sound, durable, of uniform quality and free from thin, flat and shaley pieces. It shall contain not less than 65% of calcium carbonate, except in cases of dolomitic limestone, when the sum of the percentage of calcium carbonate and magnesium carbonate shall be not less than 70%. The stone should show in the abrasion test a loss of not more than 6%, a factor of hardness of not less than 15 and a toughness of not less than 6.

"Slag for Wearing Course. The broken slag shall be clean, sound, durable and of uniform quality and shall contain not less than 32% of silica and not more than 25% of calcium oxide and not more than 1½% of sulphur. Slag shall show in the abrasion test a loss of not more than 10%, a hardness of not less than 16 and a toughness of not less than 5. Slag aggregates shall weigh not less than 75 lb per cu ft."

Oakland, Cal., Specifications for Broken Stone of the Wearing Course. For method of use, see Art. 11, Method G.

"Broken Stone for the Top Course shall be sound, hard, tough and have irregular cleavage. It shall be free from lumps of clay, loam, or other foreign materials, and shall have clean, fresh surfaces. It shall be of such size that all will pass a screen having circular openings 2½ in in diameter; at least 90% will pass a screen having circular openings 2 in in diameter, and at least 85% will be retained on a screen having circular openings ¾ in in diameter, and at least 75% shall be the run of the crusher between said 2-in and 1-in sizes. Not more than 1% may pass a screen having 1/16-in circular openings. The stone shall all be of such quality that it will not lose by abrasion more than 28% of its original weight in the rattler test.

"Screenings for the Top Course shall be of such size that all will pass a screen having circular openings ¾ in in diameter and at least 95% be retained on a screen having 1/16-in circular openings, and shall be the run of the crusher between said

sizes. Screenings shall be broken from rock of the quality herein specified for the top course, excepting that all screenings used after the last oiling shall be from rock that will lose not more than 20% of its original weight in the rattler test prescribed for top-course broken stone.

"Rattler Test. The aforesaid rattler tests shall be conducted in the rattler used for this purpose in the laboratory maintained by the Street Department of the City of Oakland. Samples for this test shall be selected by shoveling broken stone from the street, screening as hereinafter described, and revolving 100 lb of the broken stone in the rattler at a rate of not less than 28 nor more than 30 rev per min. For the base course the sample shall be shaken on two hand screens having circular openings respectively 4 in and 1½ in in diameter until 100 lb is obtained that passes the larger screen and is retained on the smaller; and the revolutions of the rattler shall continue until it has revolved 1500 times. For the top course the sample shall be shaken on two hand screens having circular openings respectively 2 in and 1 in in diameter until 100 lb is obtained that passes the larger screen and is retained on the smaller; and the revolutions of the rattler shall continue until it has revolved 5000 times."

7. Bituminous Materials

The bituminous materials which have been used successfully in the construction of bituminous pavements built by penetration methods, include asphalts, refined water-gas tars, refined coal-gas tars, combinations of refined tars, and combinations of refined tars and asphalts.

Conclusions on Suitable Bituminous Materials by Hubbard (38a). "The bituminous material used in the construction of a bituminous macadam pavement is the same for both applications. It may be a comparatively soft petroleum asphalt, fluxed native asphalt, or a heavy refined tar. The function of a bituminous cement in the bituminous macadam is not so much to hold the wearing course up as to keep the large stone fragments down under traffic. The keyed stone itself has sufficient bearing quality or mechanical stability to carry traffic and it is therefore possible to use a much softer cement than for the same thickness of fine aggregates which lack inherent mechanical stability. The cements most advantageously used are, however, much nearer solid consistency than those which it is possible to use in the construction of a bituminous carpet alone. In general, it is advisable to use a softer tar product than petroleum or asphalt product."

Forms of Reports for bituminous materials, as follows, were adopted at the first conference of State Highway Testing Engineers and Chemists, held at the U. S. O. P. R. in Feb., 1917 (53b).

"**Report on Sample of Tar.** (Classification name of material).

Laboratory No.......... (Date Reported)................, 191....
Trade name..
Identification marks..
Submitted by...............Title...................Address...............
Sampled...................., 191.... Received...................., 191....
Sampled from...
Quantity represented...
Manufactured by...
Location used or to be used..
Examined for..

TEST RESULTS

General characteristics...
Water...
Specific gravity 25° C/25° C...
Specific viscosity Engler at................° C ....
Float test............° C time..........., ...° C time.............
Melting point ° C..
Solubility in carbon disulphide...

DISTILLATION

Fractions	Character	Percentage by Volume	Percentage by Weight
170° C............			
170° C to 235° C...........			
235° C to 270° C...........			
270° C to 300° C...........			
Residue................			

Specific gravity of distillate 25° C/25° C..
Melting point of residue ° C..
Insoluble in dimethyl sulphate, percent of fraction......° C to......° C......"

Report on Sample of Asphalt Products. (Classification name of material.)

Laboratory No.......... (Date Reported)................., 191....
Trade Name..
Identification marks..
Submitted by.................Title.................Address..............
Sampled..................., 191.... Received...................., 191....
Sampled from..
Quantity represented..
Manufactured by...
Location used or to be used...
Examined for..

TEST RESULTS

General characteristics...
Specific gravity 25° C/25° C..
Flash point, ° C..
Specific viscosity Engler at...........° C.............................
Float test...........° C sec...........; ....° C sec.............
Penetration 25° C, 100 g, 5 sec.......................................
Penetration 0° C, 200 g, 60 sec.......................................
Penetration 46.1° C, 50 g, 5 sec......................................
Melting point, ° C..
Ductility.............° C............cm.............° C.............cm.
Loss at 105° C, 5 hr..
Loss at 163° C, 5 hr..
Characteristics of residue..
Penetration 25° C, 100 g, 5 sec.......................................
Consistency of residue..
Float test...........° C sec,...........; ....° C sec............
Total bitumen, soluble in CS_2......................................
Organic matter insoluble..
Inorganic matter insoluble..
Percent of total bitumen insoluble in 86° B naphtha...................
Fixed carbon..
Residue of...........penetration......................................

Sources, Manufacture, Physical and Chemical Properties, Tests, Transportation, Storage and Inspection of Bituminous Materials. See Sect. 12.

8. Specifications for Bituminous Materials

Closed, Blanket and Alternate Type Specifications for bituminous materials are fully discussed in Sect. 12, Arts. 49 and 50. In this article, the specifications of the Am. Soc. Mun. Imp. well illustrate the alternate type specifications. The Penn. State Highway Dept. specification for asphalt

cement is a modification of a typical blanket specification, as alternate requirements for different kinds of asphalt cement are given in the sections covering penetration and solubility in carbon disulphide.

The Form of Specification for Asphalt Cement for bituminous macadam pavements adopted at the first conference of State Highway Engineers and Chemists held at the U. S. O. P. R. in Feb., 1917 (53b), was as follows:

"General. The asphalt cement shall be homogeneous, free from water, and shall not foam when heated to ....° C (........° F).

"Physical and Chemical Properties. It shall meet the following requirements:

1. Specific gravity 25°/25° C (77°/77° F)..................to....................
2. Flash point.......................not less than............° C (.........° F).
3. Melting point............° C (............° F) to ....° C (........° F).
   or Ductility at......° C (......° F), not less than ....cm, or .... cm to..........cm.
4. Penetration at 25° C* (77° F), 100 g, 5 sec,................to................
5. Loss at 163° C (325° F), 5 hr....................not over.................%,
   Penetration of residue at 25° C (77° F), 100 g, 5 sec.........not less than.......
6. Total bitumen, soluble in carbon disulphide, not less than.....................%.
   a. Organic matter insoluble....................not over.................%.
   b. Inorganic matter insoluble......not over........%, or......% to.....%.

"Method of Testing. Tests of the physical and chemical properties of the asphalt cement shall be made in accordance with the methods described, or referred to on page .... of these specifications, test Nos............

"NOTES. 1. In some instances it may be considered desirable to include an 86° B naphtha solubility clause, in which case the wording should be: Percent of total bitumen insoluble in 86° B naphtha............% to ....%.

2. In some instances it may be considered desirable to include a fixed carbon test, in which case the wording should be: Fixed carbon............% to...........%.

3. In certain cases the inclusion of all the tests listed or noted may not be desirable, but it is necessary to use certain combinations of the tests in order to secure a material suitable for a specified purpose."

Am. Soc. Mun. Imp. 1917 Specifications for Asphalt Cements and Refined Tars for Bituminous Macadam Pavements:

"Previous Service. The Contractor will be required to show, to the satisfaction of the Engineer, that the Company manufacturing the asphalt cement or refined tar he proposes to use under a given specification has, for a period of at least 2 years, manufactured asphalt cement or refined tar in a thoroly equipped plant, and that asphalt cement or refined tar manufactured of bituminous material obtained from a similar source to that which he proposes to use, shall have been in continuous and successful use in bituminous pavements constructed by the mixing method or in bituminous macadam pavements for a period of at least 2 years previous to the date of the letting in which his proposal was submitted.

"Asphalt Cement A optional with asphalt cements B, C, D and refined tars E and F.

1. Asphalt cement A shall be homogeneous, free from water and shall not foam when heated to 177° C (350° F).

2. It shall show a flash point of not less than 205° C (400° F) when tested in the New York State Board of Health Closed Oil Tester.

3. Its specific gravity, at a temperature of 25° C (77° F), shall be not less than 0.960 nor more than 1.000.

4. When tested with a standard No. 2 needle by means of a standard penetrometer, it shall show penetrations within the following limits for the conditions stated, the penetrations being expressed in hundredths of a centimeter, 100 g load, 5 sec, at 25° C (77° F), from 100 to 120; 200 g load, 1 min, at 4° C (39° F), not less than 50.

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*In some instances it may be desirable to insert a requirement for penetration at the temperatures of 0° C (32° F) and 46.1° C (115° F) in which cases the clauses would read as follows:

Penetration at 0° C (32° F), 200 g, 60 sec......to...... or not less than ....
Penetration at 46.1° C (115° F), 50 g, 5 sec, ... to ...... or not over..........

5. Its melting point as determined by the cube method shall be not less than 60° C (140° F).

6. When 50 g of the material is maintained at a uniform temperature of 163° C (325° F) for 5 hr in an open cylindrical tin dish 5½ cm (about 2¼ in) in diameter, with vertical sides measuring approximately 3½ cm (about 1½ in) in depth, the loss in weight shall not exceed 2% of the original weight of the sample. The penetration of the residue, when tested as described in Clause 4 with a standard No. 2 needle under a load of 100 g, for 5 sec at 25° C (77° F) shall be not less than one-half the penetration of the original material tested under the same condition.

7. Its bitumen as determined by its solubility in chemically pure carbon disulphide at room temperature, shall be not less than 99.5%.

8. It shall be soluble in chemically pure carbon tetrachloride at room temperature, to the extent of not less than 99.5% of its bitumen as determined by Clause 7.

9. It shall be soluble in 86° to 88° B paraffin naphtha, of which at least 85% distills between 35° and 65° C (95° and 149° F), to the extent of not less than 75% nor more than 85% of its bitumen as determined by Clause 7.

10. It shall yield not less than 8% nor more than 12% of fixed carbon.

"Asphalt Cement B optional with asphalt cements A, C, D, and refined tars E and F.

1. Asphalt cement B shall be homogeneous, free from water and shall not foam when heated to 177° C (350° F).

2. It shall show a flash point of not less than 205° C (400° F) when tested in the New York State Board of Health Closed Oil Tester.

3. Its specific gravity, at a temperature of 25° C (77° F), shall be not less than 1.000 nor more than 1.080.

4. When tested with a standard No. 2 needle by means of a standard penetrometer, it shall show penetrations within the following limits for the conditions stated, the penetrations being expressed in hundredths of a centimeter, 100 g load, 5 sec, at 25° C (77° F), from 90 to 110; 200 g load, 1 min, at 4° C (39° F), not less than 15.

5. Its melting point as determined by the cube method shall be not less than 30° C (86° F).

6. When 50 g of the material is maintained at a uniform temperature of 163° C (325° F) for 5 hr in an open cylindrical tin dish 5½ cm (about 2¼ in) in diameter, with vertical sides measuring approximately 3½ cm (about 1½ in) in depth, the loss in weight shall not exceed 2.0% of the original weight of the sample. The penetration of the residue, when tested as described in Clause 4 with a standard No. 2 needle under a load of 100 g for 5 sec at 25° C (77° F), shall be not less than one-half the penetration of the original material tested under the same conditions.

7. Its bitumen, as determined by its solubility in chemically pure carbon disulphide at room temperature, shall be not less than 99.5%.

8. It shall be soluble in chemically pure carbon tetrachloride at room temperature, to the extent of not less than 99.5% of its bitumen as determined by Clause 7.

9. It shall be soluble in 86° to 88° B paraffin naphtha, of which at least 85% distills between 35° and 65° C (95° and 149° F), to the extent of not less than 75% nor more than 85% of its bitumen as determined by Clause 7.

10. It shall yield not less than 9% nor more than 13% of fixed carbon.

"Asphalt Cement C optional with asphalt cements A, B, D, and refined tars E and F.

1. Asphalt cement C shall be homogeneous, free from water and shall not foam when heated to 177° C (350° F).

2. It shall show a flash point of not less than 205° C (400° F) when tested in the New York State Board of Health Closed Oil Tester.

3. Its specific gravity, at a temperature of 25° C (77° F) shall be not less than 1.025 nor more than 1.045.

4. When tested with a standard No. 2 needle by means of a standard penetrometer, it shall show penetrations within the following limits for the conditions stated, the penetrations being expressed in hundredths of a centimeter: 100 g load, 5 sec, at 25° C (77° F), from 110 to 130; 200 g load, 1 min, at 4° C (39° F) not less than 30.

5. Its melting point as determined by the cube method shall be not less than 40° C (104° F).

6. When 50 g of the material is maintained at a uniform temperature of 163° C (325° F) for 5 hr in an open cylindrical tin dish 5½ cm (about 2¼ in) in diameter, with

vertical sides measuring approximately 3½ cm (about 1½ in) in depth, the loss in weight shall not exceed 2% of the original weight of the sample. The penetration of the residue, when tested as described in Clause 4 with a standard No. 2 needle under a load of 100 g for 5 sec at 25° C (77° F), shall be not less than one-half the penetration of the original material tested under the same conditions.

7. Its bitumen, as determined by its solubility in chemically pure carbon disulphide at room temperature, shall be not less than 99.5%.

8. It shall be soluble in chemically pure carbon tetrachloride at room temperature, to the extent of not less than 99.5% of its bitumen as determined by Clause 7.

9. It shall be soluble in 86° to 88° B paraffin naphtha, of which at least 85% distills between 35° and 65° C (95° and 149° F) to the extent of not less than 70% nor more than 80% of its bitumen as determined by Clause 7.

10. It shall yield not less than 12% nor more than 17% of fixed carbon.

"Asphalt Cement D optional with asphalt cements A, B, C, and refined tars E and F

1. Asphalt cement D shall be homogeneous, free from water and shall not foam when heated to 177° C (350° F).

2. It shall show a flash point of not less than 163° C (325° F) when tested in the New York State Board of Health Closed Oil Tester.

3. Its specific gravity, at a temperature of 25° C (77° F) shall be not less than 1.035 nor more than 1.060.

4. When tested with a standard No. 2 needle by means of a standard penetrometer, it shall show penetrations within the following limits for the conditions stated, the penetrations being expressed in hundredths of a centimeter: 100 g load, 5 sec, at 25° C (77° F), from 130 to 160; 200 g load, 1 min at 4° C (39° F), not less than 30.

5. When tested by means of the New York Testing Laboratory Float Apparatus the float shall not sink in water maintained at 66° C (150° F) in less than 120 sec nor more than 180 sec.

6. When 50 g of the material is maintained at a uniform temperature of 163° C (325° F) for 5 hr in an open cylindrical tin dish 5½ cm (about 2¼ in) in diameter, with vertical sides measuring approximately 3½ cm (about 1½ in) in depth, the loss in weight shall not exceed 3% of the original weight of the sample. The penetration of the residue, when tested as described in Clause 4 with a standard No. 2 needle under a load of 100 g, for 5 sec at 25° C (77° F), shall be not less than one-half the penetration of the original material tested under the same conditions.

7. Its bitumen, as determined by its solubility in chemically pure carbon disulphide at room temperature, shall be not less than 94% nor more than 98%.

8. It shall be soluble in chemically pure carbon tetrachloride at room temperature to the extent of not less than 98.5% of its bitumen as determined by Clause 7.

9. It shall be soluble in 86° to 88° B paraffin naphtha, of which at least 85% distills between 35° and 65° C (95° and 149° F) to the extent of not less than 75% nor more than 85% of its bitumen as determined by Clause 7.

10. It shall yield not less than 11% nor more than 14% of fixed carbon.

11. Upon ignition it shall yield not less than 1% nor more than 3% of ash.

" Refined Tar E optional with asphalt cements A, B, C, D, and refined tar F.

1. Refined tar E shall be homogeneous, free from water, and shall not foam when heated to 121° C (250° F).

2. Its specific gravity at a temperature of 25° C (77° F) shall be not less than 1.150 nor more than 1.200.

3. When tested by means of the New York Testing Laboratory Float Apparatus, the float shall not sink in water maintained at 50° C (122° F) in less than 120 nor more than 150 sec.

4. Its bitumen as determined by its solubility in chemically pure carbon disulphide at room temperature, shall be not less than 95%, and it shall show not more than 0.2% ash upon ignition of the material insoluble in carbon disulphide.

5. When distilled according to the tentative method recommended by Com. D-4, Am. Soc. Test. Mat. in 1911, it shall yield not more than 0.5% distillate at a temperature lower than 170° C (338° F); not more than 12% shall distill below 270° C (518° F) and not more than 25% shall disdill below 300° C (572° F).

6. The total distillate from the test made in accordance with Clause 5 shall have a specific gravity at a temperature of 25° C (77° F) of not less than 0.980 nor more than 1.020.

7. The melting point, as determined in water by the cube method, of the pitch residue remaining after distillation to 300° C (572° F) in accordance with the test described in Clause 5, shall be not more than 75° C (167° F).

"Refined Tar F optional with asphalt cements A, B, C, D, and refined tar E.

1. Refined tar F shall be homogeneous, free from water, and shall not foam when heated to 121° C (250° F).

2. Its specific gravity at a temperature of 25° C (77° F) shall be not less than 1.180 nor more than 1.300.

3. When tested by means of the New York Testing Laboratory Float Apparatus, the float shall not sink in water maintained at 50° C (122° F) in less than 150 nor more than 180 sec.

4. Its bitumen as determined by its solubility in chemically pure carbon disulphide at room temperature, shall be not less than 80% nor more than 95%, and it shall show not more than 0.2% ash upon ignition of the material insoluble in carbon disulphide.

5. When distilled according to the tentative method recommended by Com. D-4 of the Am. Soc. Test. Mat. in 1911, it shall yield not more than 0.5% distillate at a temperature lower than 170° C (338° F); not more than 10% shall distill below 270° C (518° F), and not more than 20% shall distill below 300° C (572° F).

6. The total distillate from the test made in accordance with Clause 5 shall have a specific gravity at a temperature of 25° C (77° F) of not less than 1.020.

7. The melting point, as determined in water by the cube method, of the pitch residue remaining after distillation to 300° C (572° F) in accordance with the test described in Clause 5, shall be not more than 75° C (167° F).

NOTES: Asphalt cements can be manufactured from Gilsonite and asphaltic oil to meet specification A; from Texas and California asphaltic oils to meet specification B; from Mexican asphaltic oils to meet specification C; from asphaltic material from Bermudez to meet specification D. Refined tars can be manufactured from water-gas tar to meet specification E; and from coal tar or a combination of coal tar and water-gas tar to meet specification F.

"Delivery. The asphalt cement or refined tar shall be delivered in suitable containers, far enough in advance of its use in the work to permit the necessary tests to be made. Each container shall be plainly labelled with the trade name of the asphalt cement or refined tar, name of manufacturer, gross weight and net weight. Each shipment and each carload shall be kept separate.

"Bills of Lading. The contractor shall furnish the Engineer on or before the arrival of each shipment at or near the site of the work, bills of lading, or correct copies thereof, which shall state the trade name of the asphalt cement or refined tar, and the name and address of the company manufacturing and supplying it.

"Samples will be taken by the Engineer from each carload of asphalt cement or refined tar when delivered at the work, unless satisfactory arrangements can be made for sampling before shipment. Such samples shall be analyzed by the Engineer to assure the delivery of an asphalt cement or refined tar of the specified quality and to determine, for purpose of payment, the quantity of bitumen.

"Work Included. Under this item the contractor shall furnish and deliver on the work at such points as directed an asphalt cement or refined tar which conforms with the specifications of any one of the asphalt cements or refined tars given above.

"Measurement and Payment. The quantity of bitumen in the asphalt cement or refined tar, to be paid for under this item, shall be the number of tons, determined in accordance with the paragraph headed SAMPLES, contained in the asphalt cement or refined tar placed in the pavement in accordance with the specifications and requirements, or used as directed for other purposes. The percentage of bitumen determined by an average of the analyses of the acceptable samples taken by the Engineer during a given month shall be used as the basis for payment for the asphalt cement or refined tar used during that month. Asphalt cement or refined tar that is wasted shall not be included in the measurement under this item. The price stipulated in this item shall include the cost of furnishing, hauling and delivering the asphalt cement or refined tar at the work, and all expenses incidental thereto."

Ohio State Highway Dept. Specifications for Asphalt Cement (46) are as follows:

"1. It shall be homogeneous in character.

cement is a modification of a typical blanket specification, as alternate requirements for different kinds of asphalt cement are given in the sections covering penetration and solubility in carbon disulphide.

The Form of Specification for Asphalt Cement for bituminous macadam pavements adopted at the first conference of State Highway Engineers and Chemists held at the U. S. O. P. R. in Feb., 1917 (53b), was as follows:

"General. The asphalt cement shall be homogeneous, free from water, and shall not foam when heated to ....° C (........° F).

"Physical and Chemical Properties. It shall meet the following requirements:

1. Specific gravity 25°/25° C (77°/77° F)................to..................
2. Flash point.......................not less than............° C (.........° F).
3. Melting point............° C (............° F) to ....° C (........° F), or Ductility at......° C (......° F), not less than ....cm, or .... cm to.........cm.
4. Penetration at 25° C* (77° F), 100 g, 5 sec,................to...............
5. Loss at 163° C (325° F), 5 hr...................not over................%, Penetration of residue at 25° C (77° F), 100 g, 5 sec.........not less than........
6. Total bitumen, soluble in carbon disulphide, not less than...................%.
   a. Organic matter insoluble..................not over.................%.
   b. Inorganic matter insoluble......not over........%, or......% to......%.

"Method of Testing. Tests of the physical and chemical properties of the asphalt cement shall be made in accordance with the methods described, or referred to on page .... of these specifications, test Nos............

"NOTES. 1. In some instances it may be considered desirable to include an 86° B naphtha solubility clause, in which case the wording should be: Percent of total bitumen insoluble in 86° B naphtha............% to ....%.

2. In some instances it may be considered desirable to include a fixed carbon test, in which case the wording should be: Fixed carbon............% to...........%.

3. In certain cases the inclusion of all the tests listed or noted may not be desirable, but it is necessary to use certain combinations of the tests in order to secure a material suitable for a specified purpose."

Am. Soc. Mun. Imp. 1917 Specifications for Asphalt Cements and Refined Tars for Bituminous Macadam Pavements:

"Previous Service. The Contractor will be required to show, to the satisfaction of the Engineer, that the Company manufacturing the asphalt cement or refined tar he proposes to use under a given specification has, for a period of at least 2 years, manufactured asphalt cement or refined tar in a thoroly equipped plant, and that asphalt cement or refined tar manufactured of bituminous material obtained from a similar source to that which he proposes to use, shall have been in continuous and successful use in bituminous pavements constructed by the mixing method or in bituminous macadam pavements for a period of at least 2 years previous to the date of the letting in which his proposal was submitted.

"Asphalt Cement A optional with asphalt cements B, C, D and refined tars E and F.

1. Asphalt cement A shall be homogeneous, free from water and shall not foam when heated to 177° C (350° F).

2. It shall show a flash point of not less than 205° C (400° F) when tested in the New York State Board of Health Closed Oil Tester.

3. Its specific gravity, at a temperature of 25° C (77° F), shall be not less than 0.960 nor more than 1.000.

4. When tested with a standard No. 2 needle by means of a standard penetrometer, it shall show penetrations within the following limits for the conditions stated, the penetrations being expressed in hundredths of a centimeter, 100 g load, 5 sec, at 25° C (77° F), from 100 to 120; 200 g load, 1 min, at 4° C (39° F), not less than 50.

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*In some instances it may be desirable to insert a requirement for penetration at the temperatures of 0° C (32° F) and 46.1° C (115° F) in which cases the clauses would read as follows:

Penetration at 0° C (32° F), 200 g, 60 sec......to...... or not less than ....
Penetration at 46.1° C (115° F), 50 g, 5 sec, ... to ...... or not over..........

5. Its melting point as determined by the cube method shall be not less than 60° C (140° F).

6. When 50 g of the material is maintained at a uniform temperature of 163° C (325° F) for 5 hr in an open cylindrical tin dish 5½ cm (about 2¼ in) in diameter, with vertical sides measuring approximately 3½ cm (about 1½ in) in depth, the loss in weight shall not exceed 2% of the original weight of the sample. The penetration of the residue, when tested as described in Clause 4 with a standard No. 2 needle under a load of 100 g, for 5 sec at 25° C (77° F) shall be not less than one-half the penetration of the original material tested under the same condition.

7. Its bitumen as determined by its solubility in chemically pure carbon disulphide at room temperature, shall be not less than 99.5%.

8. It shall be soluble in chemically pure carbon tetrachloride at room temperature, to the extent of not less than 99.5% of its bitumen as determined by Clause 7.

9. It shall be soluble in 86° to 88° B paraffin naphtha, of which at least 85% distills between 35° and 65° C (95° and 149° F), to the extent of not less than 75% nor more than 85% of its bitumen as determined by Clause 7.

10. It shall yield not less than 8% nor more than 12% of fixed carbon.

"**Asphalt** Cement B optional with asphalt cements A, C, D, and refined tars E and F.

1. Asphalt cement B shall be homogeneous, free from water and shall not foam when heated to 177° C (350° F).

2. It shall show a flash point of not less than 205° C (400° F) when tested in the New York State Board of Health Closed Oil Tester.

3. Its specific gravity, at a temperature of 25° C (77° F), shall be not less than 1.000 nor more than 1.030.

4. When tested with a standard No. 2 needle by means of a standard penetrometer, it shall show penetrations within the following limits for the conditions stated, the penetrations being expressed in hundredths of a centimeter, 100 g load, 5 sec, at 25° C (77° F), from 90 to 110; 200 g load, 1 min, at 4° C (39° F), not less than 15.

5. Its melting point as determined by the cube method shall be not less than 30° C (86° F).

6. When 50 g of the material is maintained at a uniform temperature of 163° C (325° F) for 5 hr in an open cylindrical tin dish 5½ cm (about 2¼ in) in diameter, with vertical sides measuring approximately 3½ cm (about 1½ in) in depth, the loss in weight shall not exceed 2.0% of the original weight of the sample. The penetration of the residue, when tested as described in Clause 4 with a standard No. 2 needle under a load of 100 g for 5 sec at 25° C (77° F), shall be not less than one-half the penetration of the original material tested under the same conditions.

7. Its bitumen, as determined by its solubility in chemically pure carbon disulphide at room temperature, shall be not less than 99.5%.

8. It shall be soluble in chemically pure carbon tetrachloride at room temperature, to the extent of not less than 99.5% of its bitumen as determined by Clause 7.

9. It shall be soluble in 86° to 88° B paraffin naphtha, of which at least 85% distills between 35° and 65° C (95° and 149° F), to the extent of not less than 75% nor more than 85% of its bitumen as determined by Clause 7.

10. It shall yield not less than 9% nor more than 13% of fixed carbon.

"**Asphalt** Cement C optional with asphalt cements A, B, D, and refined tars E and F.

1. Asphalt cement C shall be homogeneous, free from water and shall not foam when heated to 177° C (350° F).

2. It shall show a flash point of not less than 205° C (400° F) when tested in the New York State Board of Health Closed Oil Tester.

3. Its specific gravity, at a temperature of 25° C (77° F) shall be not less than 1.025 nor more than 1.045.

4. When tested with a standard No. 2 needle by means of a standard penetrometer, it shall show penetrations within the following limits for the conditions stated, the penetrations being expressed in hundredths of a centimeter: 100 g load, 5 sec, at 25° C (77° F), from 110 to 130; 200 g load, 1 min, at 4° C (39° F) not less than 30.

5. Its melting point as determined by the cube method shall be not less than 40° C (104° F).

6. When 50 g of the material is maintained at a uniform temperature of 163° C (325° F) for 5 hr in an open cylindrical tin dish 5½ cm (about 2¼ in) in diameter, with

vertical sides measuring approximately 3⅓ cm (about 1⅓ in) in depth, the loss in weight shall not exceed 2% of the original weight of the sample. The penetration of the residue, when tested as described in Clause 4 with a standard No. 2 needle under a load of 100 g for 5 sec at 25° C (77° F), shall be not less than one-half the penetration of the original material tested under the same conditions.

7. Its bitumen, as determined by its solubility in chemically pure carbon disulphide at room temperature, shall be not less than 99.5%.

8. It shall be soluble in chemically pure carbon tetrachloride at room temperature, to the extent of not less than 99.5% of its bitumen as determned by Clause 7.

9. It shall be soluble in 86° to 88° B paraffin naphtha, of which at least 85% distills between 35° and 65° C (95° and 149° F) to the extent of not less than 70% nor more than 80% of its bitumen as determined by Clause 7.

10. It shall yield not less than 12% nor more than 17% of fixed carbon.

"Asphalt Cement D optional with asphalt cements A, B, C, and refined tars E and F.

1. Asphalt cement D shall be homogeneous, free from water and shall not foam when heated to 177° C (350° F).

2. It shall show a flash point of not less than 163° C (325° F) when tested in the New York State Board of Health Closed Oil Tester.

3. Its specific gravity, at a temperature of 25° C (77° F) shall be not less than 1.035 nor more than 1.060.

4. When tested with a standard No. 2 needle by means of a standard penetrometer, it shall show penetrations within the following limits for the conditions stated, the penetrations being expressed in hundredths of a centimeter: 100 g load, 5 sec, at 25° C (77° F), from 130 to 160; 200 g load, 1 min at 4° C (39° F), not less than 30.

5. When tested by means of the New York Testing Laboratory Float Apparatus the float shall not sink in water maintained at 66° C (150° F) in less than 120 sec nor more than 180 sec.

6. When 50 g of the material is maintained at a uniform temperature of 163° C (325° F) for 5 hr in an open cylindrical tin dish 5⅓ cm (about 2¼ in) in diameter, with vertical sides measuring approximately 3⅓ cm (about 1½ in) in depth, the loss in weight shall not exceed 3% of the original weight of the sample. The penetration of the residue, when tested as described in Clause 4 with a standard No. 2 needle under a load of 100 g, for 5 sec at 25° C (77° F), shall be not less than one-half the penetration of the original material tested under the same conditions.

7. Its bitumen, as determined by its solubility in chemically pure carbon disulphide at room temperature, shall be not less than 94% nor more than 98%.

8. It shall be soluble in chemically pure carbon tetrachloride at room temperature to the extent of not less than 98.5% of its bitumen as determined by Clause 7.

9. It shall be soluble in 86° to 88° B paraffin naphtha, of which at least 85% distills between 35° and 65° C (95° and 149° F) to the extent of not less than 75% nor more than 85% of its bitumen as determined by Clause 7.

10. It shall yield not less than 11% nor more than 14% of fixed carbon.

11. Upon ignition it shall yield not less than 1% nor more than 3% of ash.

"Refined Tar E optional with asphalt cements A, B, C, D, and refined tar F.

1. Refined tar E shall be homogeneous, free from water, and shall not foam when heated to 121° C (250° F).

2. Its specific gravity at a temperature of 25° C (77° F) shall be not less than 1.150 nor more than 1.200.

3. When tested by means of the New York Testing Laboratory Float Apparatus, the float shall not sink in water maintained at 50° C (122° F) in less than 120 nor more than 150 sec.

4. Its bitumen as determined by its solubility in chemically pure carbon disulphide at room temperature, shall be not less than 95%, and it shall show not more than 0.2% ash upon ignition of the material insoluble in carbon disulphide.

5. When distilled according to the tentative method recommended by Com. D-4, Am. Soc. Test. Mat. in 1911, it shall yield not more than 0.5% distillate at a temperature lower than 170° C (338° F); not more than 12% shall distill below 270° C (518° F) and not more than 25% shall distill below 300° C (572° F).

6. The total distillate from the test made in accordance with Clause 5 shall have a specific gravity at a temperature of 25° C (77° F) of not less than 0.980 nor more than 1.020.

7. The melting point, as determined in water by the cube method, of the pitch residue remaining after distillation to 300° C (572° F) in accordance with the test described in Clause 5, shall be not more than 75° C (167° F).

"**Refined Tar F optional with asphalt cements A, B, C, D, and refined tar E.**

1. Refined tar F shall be homogeneous, free from water, and shall not foam when heated to 121° C (250° F).

2. Its specific gravity at a temperature of 25° C (77° F) shall be not less than 1.180 nor more than 1.300.

3. When tested by means of the New York Testing Laboratory Float Apparatus, the float shall not sink in water maintained at 50° C (122° F) in less than 150 nor more than 180 sec.

4. Its bitumen as determined by its solubility in chemically pure carbon disulphide at room temperature, shall be not less than 80% nor more than 95%, and it shall show not more than 0.2% ash upon ignition of the material insoluble in carbon disulphide.

5. When distilled according to the tentative method recommended by Com. D-4 of the Am. Soc. Test. Mat. in 1911, it shall yield not more than 0.5% distillate at a temperature lower than 170° C (338° F); not more than 10% shall distill below 270° C (518° F), and not more than 20% shall distill below 300° C (572° F).

6. The total distillate from the test made in accordance with Clause 5 shall have a specific gravity at a temperature of 25° C (77° F) of not less than 1.020.

7. The melting point, as determined in water by the cube method, of the pitch residue remaining after distillation to 300° C (572° F) in accordance with the test described in Clause 5, shall be not more than 75° C (167° F).

NOTES: Asphalt cements can be manufactured from Gilsonite and asphaltic oil to meet specification A; from Texas and California asphaltic oils to meet specification B; from Mexican asphaltic oils to meet specification C; from asphaltic material from Bermudez to meet specification D. Refined tars can be manufactured from water-gas tar to meet specification E; and from coal tar or a combination of coal tar and water-gas tar to meet specification F.

"**Delivery.** The asphalt cement or refined tar shall be delivered in suitable containers, far enough in advance of its use in the work to permit the necessary tests to be made. Each container shall be plainly labelled with the trade name of the asphalt cement or refined tar, name of manufacturer, gross weight and net weight. Each shipment and each carload shall be kept separate.

"**Bills of Lading.** The contractor shall furnish the Engineer on or before the arrival of each shipment at or near the site of the work, bills of lading, or correct copies thereof, which shall state the trade name of the asphalt cement or refined tar, and the name and address of the company manufacturing and supplying it.

"**Samples** will be taken by the Engineer from each carload of asphalt cement or refined tar when delivered at the work, unless satisfactory arrangements can be made for sampling before shipment. Such samples shall be analyzed by the Engineer to assure the delivery of an asphalt cement or refined tar of the specified quality and to determine, for purpose of payment, the quantity of bitumen.

"**Work Included.** Under this item the contractor shall furnish and deliver on the work at such points as directed an asphalt cement or refined tar which conforms with the specifications of any one of the asphalt cements or refined tars given above.

"**Measurement and Payment.** The quantity of bitumen in the asphalt cement or refined tar, to be paid for under this item, shall be the number of tons, determined in accordance with the paragraph headed SAMPLES, contained in the asphalt cement or refined tar placed in the pavement in accordance with the specifications and requirements, or used as directed for other purposes. The percentage of bitumen determined by an average of the analyses of the acceptable samples taken by the Engineer during a given month shall be used as the basis for payment for the asphalt cement or refined tar used during that month. Asphalt cement or refined tar that is wasted shall not be included in the measurement under this item. The price stipulated in this item shall include the cost of furnishing, hauling and delivering the asphalt cement or refined tar at the work, and all expenses incidental thereto."

Ohio State Highway Dept. Specifications for Asphalt Cement (46) are as follows:

"**1. It shall be homogeneous in character.**

2. It shall have a specific gravity at 25° C (77° F) of not less than 0.980.

3. Its solubility at air temperature is chemically pure carbon disulphide for the following materials, or materials similar thereto, shall be at least 99.5% for pure bitumen products, 95% for Bermudez products, 81% for Cuban products and 66% for Trinidad products.

4. It shall contain not less than 15% nor more than 28%, of bitumen insoluble in 86° B paraffin naphtha.

5. The penetration for pure bitumen products shall be between 9 and 12 mm and for fluxed native asphalts between 12 and 16 mm when tested for 5 sec at 25° C (77° F) with a No. 2 needle weighed with 100 g.

6. When 20 g of the material are heated for 5 hr in a cylindrical tin dish approximately 2½ in in diameter by ¾ in high at a temperature of 163° C (325° F) the loss in weight shall not exceed 5%. The penetration, 5 sec, 25° C (77° F), No. 2 needle, 100 g weight, of this residue shall be at least 50% of the original penetration.

7. Its fixed carbon shall be not less than 8% nor more than 16%.

8. It shall have a ductility at 25° C (77° F) of not less than 30 cm, Dow mold.

9. Of the total bitumen not more than 1% by weight shall be insoluble in chemically pure carbon tetrachloride.

10. The flash point in open cup shall be not less than 180° C (356° F).

11. It shall be free from water and shall not foam when heated to 177° C (350° F).

12. All bituminous material used in a given construction shall be uniform in character, appearance and viscosity."

Oakland, Cal., Specifications for Asphaltic Oil. For method of use, see Art. 11, Method G.

"The Oil used shall be a natural oil of an asphaltic base, treated to remove water or sediment, or the residuum of such an oil from which the volatile material has been removed by distillation. It must not have been injured by overheating, and it must not be a mixture of solid asphalt and lighter oils or distillates.

"Asphalt. The oil shall contain not less than 88% of asphalt having, at a temperature of 25° C (77° F), a penetration of 80 District of Columbia Standard. The amount of asphalt in the oil shall be determined by heating 25 g of said oil or residuum in a cylindrical metal dish in an oven, first at a temperature of 121° C (250° F) to a constant weight, and then at a temperature of 204° C (400° F) until it has reached the proper consistency when the residue shall be weighed. The metal dish specified in this test shall be between 2¼ and 2½ in in diameter, and between ¾ and 1 in in depth.

"Consistency and Volatility. When brought upon the street, the oil shall have a penetration of not less than 200 District of Columbia Standard. The oil shall lose not more than 1½% of volatile matter when heated, as above described, at a temperature of 121° C (250° F) to a constant weight. The residue in the dish, after being heated, as above described, at a temperature of 121° C (250° F) to a constant weight, shall be further heated at a temperature of 163° C (325° F) for 5 hr. The penetration of the residue after such heating shall not be less than 100 nor more than 400 District of Columbia Standard.

"Fixed Carbon. The oil shall yield not less than 3% nor more than 12% of fixed carbon.

"Organic Impurities. The oil shall contain not more than 0.2% of bituminous matter insoluble in carbon tetrachloride at temperatures between 15° and 21° C (60° and 70° F). It shall contain no free carbon and shall be free from the odor of tar.

"Adhesiveness. The oil shall show an adhesive strength of not less than 160 sec per rev when tested at a temperature of 25° C (77° F) on the Osborne Adhesive Test Apparatus in the laboratory maintained by the Street Department of the City of Oakland."

British Standard Specification for Pitch, based on specifications of the Road Board of England and adopted in 1916 by the Engineering Standards Com. of Great Britain (12).

"1. General. This pitch is suitable for pitch-grouting. See Road Board of England General Directions for Pitch-Grouting, Art. 11.

"2. Consistency. The pitch is obtained of the required consistency most conveniently by running it off from tar stills in which the distillation of the tar has been stopped at the point at which the residual pitch will give a penetration of 70, or such

other penetration as may be specified to suit climatic or local conditions, when tested at 25° C (77° F) on a penetrometer. Harder pitch may be softened or cut back, in the still or in a mixer at the tar works, to the extent necessary for it to give this penetration, by the addition of tar oil of the grade specified below in Clauses 7 to 10. Where pitch of the required consistency is not thus directly procurable, it may be prepared by softening commercial soft pitch, as specified below in Clauses 4 to 6, by the addition of tar oil as specified below in Clauses 7 to 10. In preparing the softened pitch in this manner the tar oil is added to the pitch in the manner described under Instructions for Melting the Pitch in the Road Board General Directions for Surfacing with Pitch-Grouted Macadam, in such proportions that the resultant softened pitch will give a penetration of 70, or such other penetration as may be specified to suit climatic or local conditions, when tested at 25° C (77° F) on a penetrometer, with a No. 2 needle weighed to 100 g for 5 sec.

"3. Prepared Pitch from Tar Distilleries. General Characteristics. Pitch which has been procured of the required consistency directly from a tar distillery needs only to be thoroly melted in the pitch heaters or boilers, but as a precaution against burning, 1 to 2% of tar oil may advantageously be put into the boilers with the pitch. Pitch which has been procured of the required consistency directly from a tar distillery shall not yield more than 4% of distillate below 270° C (518° F) on distillation as described in Clause 5, and shall contain not less than 16% and not more than 28% of free carbon, as defined below in Clause 6.

"4. Commercial Soft Pitch. The pitch shall be derived wholly from tar produced in the carbonization of coal, except that it may contain not more than 25% of pitch derived from tar produced in the manufacture of carburetted water-gas.

"5. Fractionation. On distillation in a litre fractionating flask, a distillation flask without special fractionating column, ½ to ⅔ filled, the pitch shall yield the proportions by weight of distillates stated below; the temperatures of distillation being read on a thermometer of which the bulb is opposite the side tube of the flask: Below 270° C (518° F), not more than 1% of distillate; between 270° and 315° C (518° and 599° F) not less than 2% and not more than 5% of distillate.

"6. Free Carbon. The pitch shall contain not less than 18% and not more than 31% by weight of free carbon. The free carbon is to be determined by the weight of the residue after complete extraction of all matter soluble in benzol or disulphide of carbon. The extraction is best carried out in a Soxhlet or similar apparatus by disulphide of carbon followed by benzol.

"7. Tar Oil. Source of Tar Oil. The tar oil to be used is preferably a filtered green or anthracene oil, and shall be derived wholly from tar produced in the carbonization of coal or from such tar mixed with not more than 25% of its volume of tar produced in the manufacture of carburetted water-gas.

"8. Specific Gravity. The specific gravity of the tar oil at 20° C (68° F) shall lie between 1.065 and 1.085.

"9. Freedom from Naphthalene and Anthracene. The tar oil after standing for ½ hr at 20° C (68° F) shall remain clear and free from solid matter, naphthalene, anthracene, etc.

"10. Fractionation. The tar oil shall be commercially free from light oils and water. On distillation in a litre fractionating flask, a distillation flask without special fractionating column, ½ to ⅔ filled, the tar oil shall yield the proportions by weight of distillates stated below; the temperatures of distillation being read on a thermometer of which the bulb is opposite the side tube of the flask: Below 170° C (338° F), not more than 1% of distillate, light oils and water, if any; below 270° C (518° F), not more than 30% of distillate, middle oils, and light oils and water, if any; below 330° C (626° F), not less than 95% of distillate, heavy oils, middle oils, and light oils and water, if any."

CONSTRUCTION

9. Mechanical Appliances

In the various methods of constructing the wearing course, the bituminous material is distributed by hand-pouring applications, gravity distributors and pressure distributors. For descriptions and factors governing

selection of vehicular distributors, see Sect. 14, Art. 6. It is evident that uniform application of the bituminous material will depend upon the suitability and the careful manipulation of the method of distribution employed. In using vehicular distributors, one cause of uneven distribution of the bituminous material is overlapping of applications. The use of strips of tar or wrapping paper, from 3 to 5 ft in width, placed at the edge of an application has prevented sections of the wearing course receiving double the amount of bituminous cement specified.

Pouring cans have been used extensively, and in some cases remarkably successful results have been secured. Their satisfactory use requires expert and painstaking supervision. Where the construction work is done by well-trained labor of a highway department and under the direction of an experienced engineer, it is possible to efficiently use this method of distribution; as examples, the Pitchmac pavements of Liverpool (see Art. 10) and bituminous macadam pavements of Alexandria, Va. (see Arts. 9 and 12) may be cited. Due to the extreme variability in the experience and quality of work of labor and contractors, the hand-pouring method should not be used on work covered by the usual type of contract (without qualification requirements) used in the United States. The same comments apply to the use of hand-drawn pressure distributors and all types of gravity distributors.

Pressure distributors vary in many details of construction and operation. It is essential, therefore, in connection with contract work to include in specifications definite requirements covering the variable factors. Unessential details should not be included as competition on contract work will thereby be curtailed. The specification should, however, include requirements which will insure the use of machines suitable for the method and the types and grades of bituminous materials employed, the prevention of formation of ruts and the disturbance of the wearing course, and ease in manipulation and supervision. As an example of a good general specification, that of the Am. Soc. Mun. Imp. is cited. Most types of pressure distributors which are drawn by road rollers or tractors or are mounted on motor truck chassis, have been employed in the construction of bituminous macadam pavements as well as for the construction and maintenance of bituminous surfaces (see Sect. 14, Art. 6). Some machines, however, have been especially designed for penetration work; as for example, a distributor having its bituminous material tank and distributing apparatus mounted on a sectional roller, the pressure being furnished by an air compressor attached to a steam road roller or tractor.

Am. Soc. Mun. Imp. Specification for Pressure Distributor. To secure uniform distribution and to provide for such details as means of control of proper pressure and temperature and prevention of rutting of the wearing course during construction, the Am. Soc. Mun. Imp. prescribed in its 1917 specifications the following requirements: "The pressure distributor employed shall be so designed and operated as to distribute the bituminous materials specified uniformly under a pressure of not less than 20 lb nor more than 75 lb per sq in in the amount and between the limits of temperature specified. It shall be supplied with an accurate stationary thermometer in the tank containing the bituminous material and with an accurate pressure gauge so located, as to be easily observed by the Engineer while walking beside the distributor. It shall be so operated that, at the termination of each run, the bituminous material will be at once shut off. It shall be so designed that the normal width of application shall be not less than 6 ft and so that it will be possible on either side of the machine to apply widths of not more than 2 ft. The distributor shall be provided with wheels having tires each of which shall not be less than 18 in in width, the allowed maximum pressure per sq in of tire being dependent upon the following relationship between the aforesaid pressure and the diameter of the wheel: For a 2-ft diameter wheel, 250 lb

shall be the maximum pressure per lin in of width of tire per wheel, an additional pressure of 20 lb per in being allowed for each additional 3 in in diameter."

Efficient Method of Using Pouring Cans in Alexandria, Va., as described by E. C. Dunn, City Engineer (28). For details of cost of construction in 1916, see Art. 12. "The standard work is built 8 in thick, the base being 5 in of locomotive cinder concrete, and the top 3 in of broken stone and asphalt. The stone herein called 1½-in stone is the crusher product between 1¼ and 2¼-in; ¾-in stone is the crusher product between ⅝ and 1¼-in; and stone chips is the crusher product between ¼ and ⅝-in.

"For the concrete a rather poor mixture is used, about 1:3½:8. As fast as the concrete is laid, it is uniformly covered with about 50 lb per sq yd of 1½-in stone, and rammed to a generally uniform surface, but not a smooth one, the object being to imbed the stone, and yet leave a rough finish. The general plane of the rammed concrete is 3 in below the finished grade with the stone projecting.

"The first course of 1½-in stone is hauled over the concrete, dumped on sheet iron plates, and shoveled into place and raked to the approximate finished grade and surface. The amount of stone in this course averages 220 lb per sq yd. Thoro rolling, a d the elimination of surface inequalities is considered necessary before the asphalt is poured.

"The first coat of asphalt, from 60 to 67% of the total amount used, is poured into the first coat of stone, diagonally across the road from 8-in spout pots, in measured lengths calculated to uniformly take the contents of a pot as averagely filled at the heating kettle. In pouring wider spaces than the ordinary the tape line is held for each pot, but always each pouring is in the opposite direction from the adjoining one. Two men do the pouring, one starting at one side of the road and the other starting at the other, and a third man, using a pot with spout opening about $^3/_{16}$ by 1 in, fills in any place not covered by the other two. Constant check is kept on the distance. Effort is made to keep the asphalt at the temperature at which it flows freely without objectionable spattering. With the asphalt in this condition the men pour a more uniform width without lapping or leaving streaks; keep a more uniform rate of speed across the road, and a thicker coating is held on the stone in the upper portion of the course than when the asphalt is at a higher temperature; and the penetration is sufficient. The pourers quickly learn the knack of walking faster when starting with the pot full and slowing up when it is emptied so that the rate of distribution is practically uniform.

"Progressively with the pouring an average of 50 lb per sq yd of ¾-in stone is spread as uniformly as possible on the asphalt immediately after it is poured. Men with street brooms follow the stone spreaders, smoothing out the stone when lumped, and covering any omitted space and the roller keeps up as close as possible in order to roll in the stone while the asphalt is hot. The rolling is continued until the stone crushes, when the entire surface is lightly broomed and then it is rolled again. The operation is repeated one or more times until the resulting surface presents a uniformity of smaller stone than that originally spread, the surface voids in the underlying course of stone apparently filled and the asphalt surface apparently covered. Some judgment should be exercised according to the material used; excessive crushing tending to produce an impervious surface over the underlying work. Usually no brooming is done after the last rolling of this coat.

"The second coat of asphalt, from 40 to 33% of the total amount used, is poured into the second course of stone in the same manner described for the first coat, except that the distance diagonal measured is laid out across the road for one half a pot and in a direction to cross the pouring lines of the first coat, and the pourers cross the road and return in pouring the full pot, and both pourers start from the same side.

"The finished coat of chips, averaging 30 lb per sq yd, is spread, rolled, broomed and rerolled as described for the second course of stone. The completed road is finished ½ in higher than grade and the ultimately compressed surface.

"The general results (of the 1915 and 1916 work) have been good to the present time (1917). No ravels, ruts or waves have developed and no bleeding sufficient to require sanding, and nothing has been spent for repairs on any section in which asphalt was used. The surface texture has become smoother each year and only a minimum of large stone show on the oldest sections. However, in comparison with the higher class pavements, the roads fall short of perfect conformity to grade and section. The slight inequalities seem hard to overcome with any justifiable expense, and are prob-

ably due to one or a combination of the following: The separation of the larger from the smaller stone in the first course; the unyielding concrete base with the small available roller used; and insufficient care at times in placing and spreading the stone. An objectional feature is that usually the work does not smooth out until the summer after the work is laid. In the interim there are the apparent necessity, and the temptation to apply a surface treatment, but as yet this has not been done on any asphalt work.

"It has been found that care for the following points tend to better uniformity in the work, and while self-evidently necessary are apt to have insufficient attention, especially in rush work: A uniformly surfaced concrete, the spreading of the first course of stone with shovels and the elimination of inequalities in this course, the lapping or the not joining of the main pouring widths, the constant check on the distance poured, the neglect of the pourers to evenly fill the entirely empty pots and the injudicious or excessive use of the spouted pot in filling in omissions. The men spreading the ¾-in stone and chips should be particularly expert. Ordinary broadcasting is not allowed. To these may be added the prompt spreading and rolling of stone on the asphalt coats and the manipulation and expert inspection of the second stone course."

10. Methods of Construction

General Considerations. In the construction of bituminous macadam pavements it is desired to secure, (1) a stable wearing course consisting of broken stone or similar material thoroly rolled so that it will be well compacted and keyed together and with the several sizes of material uniformly distributed, and (2) a uniform distribution and penetration of the bituminous material within the upper 1½ to 3 in of the crust. Several methods of construction have been devised with a view to meeting the above prerequisites. Careful supervision, based on experience, is necessary to prevent non-uniformity in the density of the wearing course of broken stone and in the amount of bituminous material applied per square yard.

Some bituminous macadam pavements are designed with the intent of constructing a pavement which, in durability, will lie between a water-bound broken stone road with a bituminous surface and a bituminous concrete. In this class, a penetration of the bituminous cement into a thoroly rolled wearing course to a maximum depth of 1½-in is desired. This type, when finished with a seal coat, has proved especially efficient. In other types, the object is to secure a bituminous coating on all particles of road metal comprising the wearing course or for at least a depth of 2 to 2½-in. There are many examples of excellent pavements constructed by this method. Pitchmac, as built in Liverpool, is one of the best types designed with the idea of constructing, by penetration methods, a bituminous wearing course which will have the characteristics of a properly constructed bituminous concrete having a mineral aggregate of broken stone, that is, all particles uniformly coated and thoroly keyed together. Due to the fact that light rolling of the broken stone prior to the application of the bituminous cement is often specified in these types, many failures have occurred due to lack of stability of the wearing course.

The pavement is generally built in 2 or 3 courses, the foundation course or courses being from 4 to 8 in thick after rolling, and the top course from 2 to 3 in after rolling. A foundation of broken stone is usually composed of the product of a crusher which passes over a screen with 1½-in circular holes and thru a screen with 2½-in circular holes, or over a 2½-in and thru a 3½-in screen, or over and thru screens having openings of similar dimensions. The foundation should be thoroly compacted with a 10 to 15-ton roller prior to the construction of the wearing course. The manner of finishing this course varies in the several methods, as will be noted later.

The crown of bituminous macadam pavements should not exceed ½ in per ft.

Conclusions. Spec. Com. Mat. Road. Cons., Am. Soc. C. E. (16f). "The crown should not exceed ½ in per ft and should never be less than ¼ in per ft.

"The principles relating to thickness applicable to a broken stone road are likewise applicable to bituminous macadam pavements, and thoro rolling, including the rolling of the upper course, both before and after the application of the bituminous material, is also necessary. As it is desired to bind only the upper course with bituminous material, it is necessary, in order to prevent waste by penetration, that there should be no appreciable voids in the next lower course. It is not necessary, however, to flush the filler or binder in this course to the same extent as is necessary in binding the top course of a water-bound road, and it is absolutely essential that no binder should cover the stones of the lower course when the top course is spread.

"The quantity of bituminous material used should be only sufficient to penetrate thru the upper course. The quantity per square yard cannot be prescribed absolutely, depending in some degree on the hardness and size of stone used, but, in general the application of 1 gal or less to the square yard for each inch in thickness of the finished upper course is adequate.

"The use of a distributor in applying the bituminous material is essential, and the distributor should be of such type that absolutely uniform application may be accomplished, and that no ruts are formed in the surface by the wheels supporting the distributor. The bituminous material should be applied at such a temperature that it will flow freely, and, to insure proper penetration, the stone should be dry and clean, and the air temperature s ould not be lower than 10° C (50° F) during application.

"In order to secure a proper surface, the covering material should preferably consist of the crusher product passing over a ¼-in screen and thru a ¾-in screen. Finer material, however, may be used for covering if a slippery surface is not objectionable but the use of material passing thru a 10-mesh sieve should be avoided.

"The use of a bituminous material by no means justifies any lack of care in the ordinary details to be followed, but rather increases the need for thoroness and skilled supervision. The main principles underlying good construction in water-bound roads remain in full force when such roads are treated with bituminous material."

Conclusions on Amount and Method of Distribution of Bituminous Material by Ill. Highway Comm. (40a). "It is necessary that the bituminous binder be spread so as to present as uniform a surface as possible. This may not necessarily mean the uniform distribution of the binder as the texture of the surface of the macadam before the application of the binder may itself not be quite uniform. Therefore, the more finely divided form in which the asphalt can be applied, the better the control of its distribution. The form of the application whereby the material is spread by a jet of steam has given excellent results. Too much binder should not be used as it will result in a less stable layer of bituminous macadam than if sufficient binder is used only to fill the voids in the stone. It is essential that the surface of the road have very close texture and that usually this can not be secured in less than three applications except by an excessive amount of binder. The most economical and best results can be secured when the binder is put on in three applications."

Conclusions on Rolling, by Hubbard (38a). "It should be thoroly compacted by rolling until the fragments of broken stone have just keyed together. It is generally believed that an excess of rolling should be avoided in order not to close up the surface to such an extent that satisfactory penetration of the bituminous material will be prevented. While this is true, the general tendency is to go to the other extreme and the almost fatal mistake is made of not rolling enough. It is a fact but little appreciated that almost all of the compaction of the large stone in the wearing course is obtained prior to application of the bituminous material. It is therefore exceedingly poor practice to merely smooth out the top course of stone before applying the bituminous material, as is required by some specifications. The rapid deterioration and unsatisfactory condition of many bituminous macadam pavements are in large measure due to lack of rolling during the initial stages of construction, which makes it difficult, if not impossible, to properly consolidate the road after application of the bituminous material. A rapid cooling of the bituminous material takes place after application, which results in a false set of the course of top stone, if it has not

previously been keyed together by rolling. In even moderately cool weather and especially after application of a layer of finer stone, this false set is difficult to completely break down by ordinary rolling. Moreover, if broken, a true set will be seldom obtained because of the thickness of the coating of bituminous material on the stone fragments which, under pressure of the roller, tend to slide about rather than to key together. The principles here involved are commonly recognized in the construction of the ordinary types of bituminous concrete pavements where compression is only attempted on well-mixed and usually preheated bituminous aggregates carrying carefully controlled percentages of bituminous material. Lack of initial rolling in a bituminous macadam is almost invariably followed by waviness and ruts produced by traffic. It may usually be detected by the comparative ease with which the top course may be pried up with a screw driver or other hand tool."

Sharples (47) states that "The greatest of care must be used in rolling this course. The surface must be well knit together, smooth and firm. At the same time it must be open enough to admit the bituminous material. The engineer must watch the stone carefully to see that it is not crushed too much, as in this case the door will be closed to the entrance of the bituminous material and it will be left as a mat on the surface instead of entering between the stones to bind them together. On the other hand the stone must not be too open, as in that case the binder will run thru to the bottom of the course. If the stone is very hard, it may be advisable to add a small quantity of ¾-in stone just previous to the last rolling, to reduce the void space. After the rolling is finished, the stone should be 2½ in in depth."

Conclusions on Crown by Meeker (16a). "In building some of the first bituminous roads in New Jersey, it was found that if a crown of ¾ or 1 in per ft was used, the surface would be slippery. The speaker believes that no road with a bituminous surface should have a crown of more than ½ in per ft, or, if the road is wide, ⅜ in per ft is ample. If a proper crown is used, the objection of slipperiness can be prevented by immediately covering any bituminous application with a layer of stone screenings or sharp sand, and in this way a fairly gritty surface may be obtained."

Method A. In this method, the road metal of the wearing course, which is laid on a foundation course as described above, consists of one product of broken stone, ranging in size from a product whose particles vary from 1½ to ½-in in longest dimensions to a product passing over a 1½-in and thru a 2½-in screen, or similar thereto. A typical mechanical analysis of a product, the use of which has given satisfactory results, follows:

Passing ¼-in screen, trace
Passing ½-in screen, 18.9%
Passing ¾-in screen, 43.1%
Passing 1-in screen, 34.4%
Passing 1¼-in screen, 3.6%

After the wearing course is laid the bituminous material is applied, either before or after the broken stone is rolled, some engineers preferring the former method because of the greater depth of penetration secured. To secure the best results, the wearing course should be thoroly rolled prior to the application of the bituminous material in order to secure a well compacted and stable course of broken stone, mechanically interlocked and bound together. If the rolling is postponed until after the application of the bituminous material, the wheels of the roller may have to be wet or oiled to avoid picking up the surface. After the application of the bituminous material, a coat of mineral matter should be spread over the surface of the course and rolled. The total amount of bituminous material used in this method varies from ½ to 2½ gal per sq yd. For specifications, see Art. 11, Method A.

Method B. In case the metalling of the wearing course is a uniform product of about 1 or 1½-in in size or a product similar to or larger than one passing over a 1½-in and thru a 2½-in screen, usually the voids in the upper part of the wearing course are filled after the bituminous cement is

applied. Practice varies with reference to the amount of rolling of the wearing course prior to the application of the bituminous cement. For traffic, medium or heavy in weight and amount, the best results have been secured by thoroly rolling the road metal and thus securing maximum interlocking of the particles and thereby obtaining the highest degree of stability practicable by this method. The bituminous cement is applied in an amount varying from 1½ to 2 gal per sq yd, after which ⅜-in stone chips or a product similar to one passing a ½-in and thru a 1-in screen is spread and thoroly rolled. Usually the surface is then broomed with stiff brooms, removing the excess loose broken stone, and another coat of bituminous cement, from ½ to 1 gal per sq yd, is applied, covered with a layer of stone chips or pea gravel and rolled. For specifications, see Art. 11, METHOD B.

Strong (51), when constructing a wearing course of broken stone which is less than 2½-in and greater than 1½-in and employing broken stone less than 1½-in and greater than ⅝-in for the filler after the first application of the bituminous cement is deposited, uses the following rules for the total amount of bituminous cement to be used, dependent upon the physical properties of the broken stone employed. In cases where the stone is of low crushing and abrasive strength, a total of 0.9 gal is used for each inch in depth of the compacted wearing course. In cases where the stone is of better material such as trap, 0.82 gal is used for each inch in depth of compacted wearing course. The total amount of bituminous cement is applied in two applications, the first to be ⅔ of the total amount and the second, applied after the filler is spread, rolled and the surplus removed, ⅓ of the total amount. It is insisted that the applications of bituminous cement should be made with pressure distributors. If hand pouring is used it is dangerous to attempt to use the above quantities as uneven distribution of the binder, which is unavoidable, invariably leads to the development of fat spots.

Method C. This method is often used when the road metal composing the wearing course varies from 2 to 3½-in or from 2½ to 4-in. After lightly rolling the wearing course, coarse sand, stone chips or pea gravel is spread and broomed until the voids of the metalling are partially filled. Usually the road metal is again lightly rolled and any surplus material is broomed off the surface. The bituminous cement is then applied, using from 1¼ to 2 gal per sq yd. This coat is covered with a layer of pea gravel, screened stone chips or larger broken stone and thoroly rolled. Sometimes a seal coat of from ½ to 1 gal of bituminous cement is used with this method. For specifications, see Art. 11, METHOD C.

Ohio State Highway Dept. Method Using Soft Stone (30b). "The usual specifications for bituminous macadam pavements limit the size of the stones composing the surfacing material to a maximum that will pass a 2½-in ring. These specifications have given satisfaction with trap rock and granite, but with softer varieties of rock such as limestone there is a tendency for the stone to powder and crush under the roller and to wear under traffic, which makes a larger sized aggregate desirable. To meet these conditions the Ohio State Highway Dept. has been experimenting with the use of a surfacing stone that will pass a 4-in ring and be retained on a 2½-in ring. The voids in this material are partly filled with sand, stone dust and chips, altho thoro rolling ordinarily breaks up enough of the material to make a fairly compact layer.

"The method of construction is to spread and harrow the stone as for a water-bound macadam road. As soon as the stone is partly compacted, stone chips and stone dust are spread into the voids with shovels. Rolling and the application of screenings are continued until the layer of stone is thoroly compacted and the voids sufficiently filled so that the amount of bituminous material to be used will produce a dense mixture. The bituminous binder is applied by the penetration method with any approved form of apparatus. After the application of the bituminous binder the surface of the pavement is spread with screened washed gravel ¼ to 1 in in size. After rolling

the gravel in, a seal coat of the same bituminous material is applied and more gravel is added, followed by more rolling. A total application of about 2 gal per sq yd for a 3-in depth of rolled stone gives excellent results. Washed gravel instead of limestone chips is used, as the available gravel is usually harder and tougher than ordinary limestone and the cost is about the same. A finer gravel, ¼ to ⅝-in, is preferable for the seal coat. For a 4-in road the amount of bituminous binder required is about 2¼ gal per sq yd. It is reported that these pavements have given much better satisfaction than the older ones that were constructed with the 2½-in stone as aggregate."

Method D. A bituminous macadam pavement called Pitchmac by its inventor J. A. Brodie, City Engineer of Liverpool, has been used to a considerable extent in England and has been adopted as a standard type by the Road Board of England. It is constructed on a foundation of stone. The wearing course of broken stone varies from 2 to 4½ in in depth, dependent upon traffic conditions. If the wearing course is from 2 to 3 in in thickness, it is constructed in 1 layer, and if from 4 to 4½ in, in 2 layers. The single layer and, in the case of 2 layers, the upper layer is composed of broken stone ranging in size from 1¼ to 2½ in. After thoro rolling the bituminous material is applied to the single layer or to each of the layers of the 2-layer wearing course. The bituminous compound used in England consists of hot sand mixed with tar pitch. From 1¼ to 2 gal per sq yd are used for the 1-layer wearing course and from 3¼ to 3½ gal for two layers. To assist in completely filling the voids, chips varying in size from ⅜ to ¾ in are applied during the rolling of the bituminous grouted layer. This type of pavement has been used to a limited extent in Massachusetts, see (24). For specifications for the bituminous mastic used in England, see Art. 7, and for the construction specifications of the Road Board of England and Massachusetts, see Art. 11.

Liverpool Practice. Brodie states (5) that "pitch grouted macadam has been found to give most satisfactory results in streets of medium and light traffic, and is now being largely used in place of ordinary macadam, and also of more expensive pavements. It is laid to a depth of from 3½ to 4½ in, in two layers. Welsh granite macadam is used, broken to a 2½-in gauge for the lower layer and to 1½-in for the top surface. Each layer is put down dry and continually rolled before and after the grouting of pitch and sand mixture has been applied, until the surface is thoroly consolidated. The foundation is generally of hand-pitched rock, 10 in deep as for ordinary macadam, but in some cases a bed of 6-in concrete has been used on main roads. Pitch macadam is also being much used as a surface covering for old boulder pavements, many of which still exist in Liverpool in old streets where the traffic is very small. The cost of pitch macadam may be taken at 1s (24 cents) per sq yd per in of depth.

"The oldest sample of pitch macadam in Liverpool was laid in Princess Ave. in 1901, near the end of Eversley St., and has been in continuous use ever since without repair. Other lengths of pitch macadam in this avenue were laid at various dates between 1906 and 1908. This avenue carries a large volume of light motor and carriage traffic, as well as some of a heavier character, the traffic amounting to 120 000 tons per yd width per annum."

Method E. When the metalling of the wearing course is of a large and uniform size, another method employed is to place a layer of sand ¾ in thick on the bottom course, the voids of which have been filled. The bituminous cement is then distributed on this layer, using about 1 gal per sq yd. The upper course of metalling is immediately placed on the mastic and rolled. Continued rolling forces the material of the upper course down and draws the bituminous mastic up into the voids. A coat of bituminous cement, using about 1¾ gal per sq yd, is then applied to the surface of the upper course. A layer of ⅜-in stone, ½ to ¾ in thick, is spread over this and rolled. The work may stop here or may be carried on a step further

by brooming off the excess $\frac{3}{8}$-in stone, afterwards applying another coat of bituminous cement, $\frac{1}{2}$-gal per sq yd, adding a layer of screened stone chips and rolling the same. The Gladwell system, as used to a limited extent in England, is essentially the same in principle except that a course of screened stone chips mixed with bituminous material is substituted for the sand layer and its coat of bituminous material. For specifications, see Art. 11, METHOD E.

Method E Used with a Cement-Concrete Foundation as described by Brigham (22). "The top-course specifications called for cleaning the concrete, after which high-carbon binder tar was applied at the rate of $\frac{1}{2}$ gal per sq yd. The tar was heated to about 121° C (250° F) in the tank cars in which it was shipped, and applied at from 40 to 50 lb pressure. The pressure distributor was hauled by a tractor, which also furnished steam to run the air-pressure pump. Immediately after applying the tar, $\frac{3}{4}$-in stone was spread, only enough being used to keep the tar from picking up while being rolled. A 10-ton roller was then started, and the rolling and spreading continued together until about 1-in, loose measure, of $\frac{3}{4}$-in stone was applied. Enough of this size stone was used so that no tar came to the surface, yet each stone was bedded in tar. A second application of tar, $\frac{1}{2}$ gal per sq yd, was distributed as described, and this was covered at once with a thin layer of screenings. As before, the rolling and spreading of the stone were carried on simultaneously. It required about $\frac{3}{4}$ in, loose measure, of screenings to prevent the pavement from bleeding. In building this top course it was found that the first layer of stone could be rolled too much, forming a thin layer of dust to which it was hard to make the second coating of tar bind, but thoro rolling of the second application improved the pavement. With an average of 5 men sweeping and 15 men spreading stone, the progress was about 1500 lin ft of finished wearing course a day.

"The cost per square yard of the pavement was as follows: 1 : $2\frac{1}{2}$: 5 concrete foundation, 5 in thick, \$0.708; top course, including stone and tar, in place, complete, \$0.2225; total cost of pavement, \$0.9305.

"For comparison there are listed below the average costs per square yard of several of the common types of pavement built in this section of New York State and compiled from data in the 1915 Bulletin of the Highway Comm.: Water-bound macadam, 15 roads, \$0.737; water-bound macadam with hot or cold oil surfacing, 13 roads, \$0.8103; grouted bituminous macadam, 23 roads, \$0.946; concrete pavement, 27 roads, \$1.117; 1 : $2\frac{1}{2}$: 5 concrete foundation with open mix bituminous concrete top course, 7 roads, \$1.335.

"It is readily seen from the foregoing data that in first cost the tar-macadam top course on a concrete foundation is nearly the same as the grouted bituminous macadam and considerably less than concrete pavement. In regard to these three competing types of medium-priced pavements, the composite type has many distinct advantages. Practically all failures of macadam roads can be traced to poor foundation. The stone of the lower courses sinks into any soft spots in the subgrade and the top course follows. This forms a pot-hole which is a source of constant trouble and maintenance expense and makes a rough road for the traveling public. In a pavement with a concrete foundation, the concrete bridges over these weak points in the subgrade, thus eliminating one of the worst features of an all stone pavement. Concrete pavement, while a type requiring little maintenance, is high in first cost, needs care in construction and in the choice of the materials used as ingredients, and is slippery and hard for horse traffic. No expansion joints are needed in the composite type of pavement, as the bituminous macadam mat keeps moisture and temperature conditions constant in the slab, thus protecting it from extreme changes resulting in cracking and displacement. Should the base crack, as it is not exposed to traffic, it requires no maintenance. The only maintenance necessary for this pavement, therefore, is to patch the wearing course as weak spots develop and to clean ditches and culverts. Possibly every 3 or 4 years a light oil should be applied to enliven the old bituminous material. This leaves the composite type of pavement with the following advantages: Low first cost; low annual maintenance charge; simple to construct; less care in selecting the materials entering into its structure; permanent base on which to build any type of surfacing, should the original wear out; and smooth and resilient surface for automobilists and horsemen."

Method E. Gladwell System as described by Gladwell and Manning (7).

BITUMINOUS BINDER. "The bituminous binder or matrix used under this system is composed of clean, thoroly dried granite chippings, free from dust, and such as will pass thru a ¼-mesh sieve. The procedure to be followed in the manufacture of the binder is to dry the chippings in an ordinary hot plate or portable sand drier, and, when still warm, but at a temperature not exceeding 38° C (100° F), mix with a refined tar. The composition is heated to about 79° C (175° F) and is then thoroly incorporated with the chippings, by applying the liquid gradually, and turning the mass until the whole forms a lively, plastic, bituminous matrix or binder. A mixture consisting of 15 gal of composition per 1 cu yd of chippings is a practical average composition.

LAYING THE AGGREGATE. "Upon the foundation already prepared and cleaned, lay a cushion of the prepared matrix or sub-binder, say about 6 ft in length and to the half width of the road, using 1 cu yd of sub-binder for each 46 sq yd of surface, or thereabouts; this should be spread evenly and lightly, and on no account should it be tramped on or consolidated until the aggregate is spread as hereunder described. This stone should be clean and true to gauge, preferably 2-in to 2½-in. The average road stone broken to 2-in gauge will cover 11 to 12 sq yd per ton as a two-stone coat. Spread the same as closely and evenly as possible, giving a two-stone coat, and using ordinary stone forks, so as to leave the smaller flaky pieces of stone, as well as all dust and rubbish, behind as waste. By adopting and repeating this method the men will be enabled to lay both sub-binder and aggregate without trampling on either. Take care that a raw edge of sub-binder and aggregate is always left at the half-way width of the road, to ensure a satisfactory joint when the remaining half-way width is re-surfaced.

ROLLING THE AGGREGATE. "Rolling should be commenced as soon as a section of about 25 or 30 yd in length has been laid, the metalling gang being kept as busily employed as possible in laying a further length of materials. The best results under this system will be found to accrue from the use of a fairly light roller, the object being to gently press the aggregate down into the sub-binder, and at the same time to entice the latter in an upward direction so as to fill the voids in the aggregate. The roller should be driven over the newly-laid materials at its lowest speed, and after a few journeys over the surface it will be found that the sub-binder is working up between the voids in the aggregate; immediately apply to the newly-rolled surface by sprinkling, not entirely covering, some of the same material as has already been referred to as the sub-binder, but which now becomes the top or super-binder. Lightly brush this super-binder into the surface voids in the aggregate until the same are fairly well filled, and continue rolling until the new surface of the road is solid.

SEALING THE SURFACE. "The surface should be sealed, which is carried out by either one or other of the following methods. In warm, dry weather, a considerable superficial area of road may be surface sealed at one operation, by means of one of the mechanical tar-spreading machines. If a mechanical spreader is used, it will be advisable to use a larger percentage of the super-binder than when hand-sealing is resorted to, while the quantity of composition necessary will be somewhat reduced, 1 gal being considered sufficient for 6 or 7 sq yd. If it is considered preferable to surface-seal the road as the work proceeds, this can be readily done by hand labor. The quantity of tar used in carrying out this operation varies in proportion to the quantity of super-binder used in the consolidation, and the amount of rolling the road has received, and will be found to range from ¼ to ½ gal per sq yd. One ton of ¼-in gauge granite chippings will be found sufficient to easily cover 150 sq yd of sealed surface. After the chippings are spread, the road should be well rolled and thoroly compacted."

Method F. In order to secure uniform sizes of road metal in the course upon which is to be applied the first application of bituminous binder, in some cases recourse has been had to harrowing. After harrowing, the course is shaped and thoroly compacted before the bituminous material is applied. With the limestones commonly used in Illinois, this method has produced satisfactory results when suitable asphalt or tar cements have been properly used in accordance with the specification of the Ill. State Highway Dept. For details of construction, see Art. 11, METHOD F.

Method G. In some cases, when heavy asphaltic oil has been used for the bituminous cement, the following method has been employed. Upon a course of broken stone, prior to rolling, about ½ gal per sq yd of asphaltic oil is distributed. The course is then harrowed, after which the second application of about ½ gal per sq yd is made. The course is next thoroly rolled during which screenings are spread. In some cases the pavement is finished by a third application of ½ gal per sq yd of oil, screened and rolled. In other cases, the third treatment is followed by a fourth using from ¼ to ⅓ gal per sq yd. See Oakland, Cal., specifications, Arts. 6, 8 and 11.

Bituminous Gravel Pavements. The use of gravel in the construction of bituminous pavements by penetration methods has been usually limited to those localities where broken stone costs more than gravel. It is self-evident that it is impracticable to secure the same keying effect with gravel as can generally be obtained with broken stone.

Bituminous Gravel Pavement in Longview, Texas. The method of construction and the conclusions relative thereto, as contained in the following abstracts of a description by Green (37), are typical of the practice of many engineers who have used gravel in this class of work.

"Crushed limestone delivered on the streets cost about $3.25 per yd, and even at that price was not the best material, being soft and dusty. A good quality of washed gravel was available at a price delivered on the street of about $2.20 per cu yd. Gravel is, however, rather unsuitable for use in making a wearing surface which depends on bituminous cement for its bond. The reason for this is that gravel, being generally round and weather-worn, does not lock well together, and the strength of the wearing surface is dependent almost entirely on the bond of the bituminous cement. It was necessary, however, to decide which was to be preferred under the circumstances. The limestone had better locking qualities, but was high in first cost, and the amount of money available was limited. It was decided therefore to use the gravel and make every effort to lock or bond it by rolling.

"It was specified that the gravel, as spread on the street, should be of a size that would pass a ring of 2-in diameter and be held on a ring of ½-in diameter. After a small yardage had been spread under these specifications, it was found that there was no lock at all between the stones, and that when filled with the bituminous cement but little strength was secured. This yardage was taken up and the gravel afterwards used was still further screened so as to eliminate practically all pebbles below ¾ in in size. After the surface had been rolled to the satisfaction of the inspector, 1½ gal per sq yd of Texaco asphalt was poured over the pavement, and, immediately behind the asphalt, pea-size gravel was lightly spread over the surface, and the whole rolled again. This was then covered with ½ to ¾ gal per sq yd of asphalt cement, and over this second coat of cement was spread coarse sand, and the whole again rolled.

"On account of the fact that so much care had to be taken with the gravel used, and that it all had to be screened after being received in order to eliminate small pebbles which prevented the locking together of individual stones, it would probably have been cheaper to have purchased crushed limestone in the first place. Some conclusions may be drawn as to this method of construction. They are as follows: Gravel can be made to lock and bond only after a great deal of labor and trouble are taken with it. It would probably be economical to pay twice as much for crushed stone as for gravel to get equal results."

11. Specifications for Construction

The fundamental characteristics of methods of construction, A to F, under which the following specifications are classified, are described in Art. 10.

Method A. The 1917 Dallas, Texas, Specifications are as follows:

"**Asphalt Macadam Wearing Surface.** Upon this foundation crushed Jacksboro

limestone, 1½ to ⅜ in in size, shall then be evenly spread to such thickness that after thoroly rolling with a 10-ton roller it shall conform with the grade of the completed street.

"Asphalt, heated by means of an improved form of heater, to a temperature of not less than 149° C (300° F) and not more than 204° C (400° F), shall then be applied by means of an approved distributing device, which will spread the asphalt over the surface in the proper quantity. Twenty pounds of asphalt shall be used to each square yard of surface. No asphalt shall be applied to the street surface when the stone is wet, nor when the temperature of the air is less than 15° C (60° F).

"Hot crushed Jacksboro limestone chips shall then be evenly spread over the street surface, rolled until cool and the entire street surface conforms to the true grade and cross-section of the completed street."

Method B. Am. Soc. Mun. Imp. 1917 Specifications. For sections covering broken stone, see Art. 6; for sections covering bituminous cements, see Art. 8.

" General Description. The bituminous macadam pavement shall consist of three courses of broken stone, separately constructed, laid to conform to the required grades and cross-sections, and constructed as hereinafter specified with bituminous material incorporated with the top or third course.

" First Course. After the subgrade or subbase course shall have been prepared as specified, a course of No. 4 broken stone shall be evenly spread so that it shall have, after rolling, the required thickness of 3½ in. The depth of loose broken stone shall be gauged by the use of strings between iron stakes, as directed. The spreading of the broken stone must be from piles dumped on boards provided for the purpose or from piles dumped alongside the road, or as directed by the Engineer. This course shall be thoroly rolled with a 12 to 15-ton road roller. The initial rolling shall begin at the sides of the road and continue towards the center and shall be kept up until the stone is keyed together and there is no disturbance of the stone ahead of the roller. After the first course has been compacted, it shall be evenly covered with a thin layer of screenings. The quantity of screenings to be used shall be just sufficient to cover the larger stones and care shall be exercised to avoid the use of an excess of the screenings. This covering shall then be rolled as heretofore provided except that water shall be used in connection with the rolling as follows: After the screenings shall have been lightly rolled, water shall be sprinkled on the road surface just ahead of the roller, in such quantity as will prevent the sticking to the wheels of the roller of the fine material on the surface, and the combined spreading of screenings, watering and rolling shall be continued until the voids of the broken stone become so filled with the finer particles as to result in a wave of grout being pushed along the road surface by the front wheel of the roller. After the completion of the rolling, no teaming other than that necessary for bringing on the broken stone for the next course shall be allowed over the rolled broken stone. Should it be apparent after the rolling of the first course that the subgrade material shall have become churned up into or mixed with the broken stone of this course, whether by reason of the rolling, or by hauling over the broken stone or otherwise, the contractor shall at his own expense remove and replace such mixture of subgrade material and broken stone with clean broken stone of the proper size and shall roll the material to produce a uniform, firm and even first course as required.

" Second Course. On the completed first course shall be spread, in the manner specified in the preceding paragraph, No. 4 broken stone to form the second course. This broken stone shall be evenly spread to such a depth that it shall have, after rolling, the required thickness of 3½ in. The second course shall be compacted, puddled with screenings and water, and finished under the same provisions as prescribed for the first course. When the rolling shall have been completed, the surface of the second course shall be firm, even and true to the lines, grades and cross-sections. If the surface is not slightly rough so as to afford a sufficient mechanical bond for the third course, it shall be broomed.

" Description of Top Course. The top course of the bituminous macadam pavement shall consist of a third course of broken stone and two applications of bituminous material, each application being followed by the distribution of a layer of No. 1 broken stone, constructed as hereinafter specified.

"**Asphalt Cement and Refined Tar.** The asphalt cement or refined tar, hereinafter referred to as bituminous material, used in the construction of the third course of the bituminous macadam pavement shall conform with either one of the specifications covering the chemical and physical properties of bituminous materials included under the item entitled 'Asphalt Cements and Refined Tars for Bituminous Macadam Pavement.' See Art. 8.

" **Heating Bituminous Materials.** Bituminous materials shall be heated in kettles or tanks so designed as to admit of even heating of the entire mass, with an efficient and positive control of the heat at all times. Asphalt cement shall be heated as directed by the Engineer to a temperature between 135° C (275° F) and 177° C (350° F). All asphalt cement heated beyond 177° C (350° F) shall be rejected. Refined tar shall be heated as directed by the Engineer to a temperature between 93° C (200° F) and 121° C (250° F). All refined tar heated beyond 121° C (250° F) shall be rejected. No tar shall be heated in kettles or tanks containing any oil or asphalt cement. Before changing from one type of material to another, kettles or tanks shall be scrupulously cleaned in order to avoid mixtures of the two. Any mixtures of different kinds of bituminous materials shall be rejected.

" **Thermometers Furnished by Contractors.** The contractor shall provide a sufficient number of accurate, efficient, stationary thermometers for determining the temperature of the bituminous material in kettles or tanks.

" **Third Course of Broken Stone.** On the completed second course, when thoroly dry, shall be spread, in the manner above specified for the first course, dry No. 3 broken stone to form the third course. This broken stone shall be evenly spread to such a depth that it will have, after rolling, the required thickness of 2½ in. The third course shall be thoroly compacted by dry rolling until the fragments of broken stone have keyed together in accordance with the same provisions covering rolling as prescribed for the 'First Course.'

" **First Application of Bituminous Material.** After the third course of broken stone shall have been thoroly compacted as specified and when clean and thoroly dry, the bituminous material shall be uniformly applied over the prepared surface of the third course by means of a pressure distributor as hereinafter specified. The asphalt cement, when applied, shall have a temperature between 135° C (275° F) and 177° C (350° F). The refined tar, when applied, shall have a temperature between 93° C (200° F) and 121° C (250° F). The total amount of bituminous material to be used in the first application shall not be less than 1½ gal nor more than 1¾ gal per sq yd, the precise quantity being determined by the Engineer.

" **Pressure Distributor.** See Art. 9.

" **First Application of No. 1 Broken Stone.** Immediately after the application of the bituminous material, a layer of dry No. 1 broken stone, not to exceed ⅜ in in thickness, shall be spread as directed by the Engineer over the surface of the bituminous material and shall be at once rolled as directed by the Engineer with a roller weighing between 12 and 15 tons. During the rolling process, additional No. 1 broken stone shall be applied and broomed until the voids in the upper portion of the third course are filled to the satisfaction of the Engineer.

" **Second Application of Bituminous Material.** Prior to the second application of bituminous material, all loose No. 1 broken stone shall be swept from the surface of the pavement. When thoroly clean and dry, a second application of bituminous material shall be uniformly applied over the surface by means of a pressure distributor as specified above. When applied the asphalt cement shall have a temperature between 135° C (275° F) and 177° C (350° F). When applied the refined tar shall have a temperature between 93° C (200° F) and 121° C (250° F). The total amount of bituminous material to be used in the second application shall not be less than ½ gal nor more than ¾ gal per sq yd, the precise quantity being determined by the Engineer.

" **Second Application of No. 1 Broken Stone.** Immediately after the second application of bituminous material, a layer of dry No. 1 broken stone, not to exceed ⅜ in in thickness, shall be spread and broomed as directed by the Engineer over the surface of the bituminous material and thereafter at once rolled as directed by the Engineer with a roller weighing between 12 and 15 tons. The rolling shall be continued and additional No. 1 broken stone shall be applied until a smooth, uniform surface is produced to the satisfaction of the Engineer.

"**Seasonal and Weather Limitations.** No bituminous material shall be applied when the air temperature in the shade is below 10° C (50° F), except by the written permission of the Engineer.

"**Measurement and Payment.** The quantity of bituminous macadam pavement to be paid for under this item shall be the number of square yards, measured horizontally, satisfactorily completed in accordance with the specifications. The price stipulated in this item shall include the furnishing, crushing and screening of the different sizes of broken stone, the heating and distributing of the bituminous material, and all materials, work and expenses incidental to the completion of the bituminous macadam pavement except the furnishing of the bituminous material, which will be included for payment under the item entitled Asphalt Cements and Refined Tars for Bituminous Macadam Pavements." See Art. 8.

Method B. The 1917 Penn. State Highway Dept. Specifications are as follows:

"**Crushed Stone.** The stone shall be first quality, cubical crushed rock, free from dirt, dust and foreign materials and of such size as shall pass a 3-in revolving screen and be retained on a 1-in screen. No intermediate sizes shall be removed. The French coefficient of wear shall be not less than 10. For filling the surface voids in the above described stone after the bituminous material has been applied, hard, tough crushed rock, free from dirt, dust and foreign materials, passing a 1-in revolving screen and being retained on a ½-in screen and having a French coefficient of wear of not less than 15, shall be used. This stone is known as ¾-in material.

"**Stone Chips.** The stone chips shall be of the best quality rock and of such sizes as shall pass a ⅝-in screen, with the larger sizes predominating and shall be free from dirt, dust and foreign materials. The French coefficient of wear shall be not less than 15.

"**Placing.** The broken stone shall be spread upon the base course, with shovels, from piles alongside the roadway or from a dumping board. In no case shall the broken stone be dumped directly upon the base course. The depth of the surface course shall be not less than 3 in at any point after final compression. If a greater depth is laid by the contractor no extra allowance for such additional depth will be made.

"**Rolling.** After the broken stone for the surface course has been laid true to line, grade and cross-section, it shall be rolled with a power roller, weighing not less than 10 tons, until the stone is compressed to a firm, even surface, but not to final compression.

"**Bituminous Application.** After the rolling has been completed as above there shall be spread evenly over the surface a quantity of approved bituminous binder, not less than 1¼ nor more than 1½ gal, as directed, to each sq yd of surface area. The bituminous material shall be heated to and applied at a temperature of not less than 107° C (225° F) nor more than 163° C (325° F), if an asphalt, and not less than 79° C (175° F), nor more than 121° C (250° F), if a tar product, as may be directed. After the bituminous binder has been applied, there shall be spread a layer of ¾-in dry crushed rock free from dust and in such quantity as just will cover the surface and fill the surface voids. Rolling then shall continue until the surface is bonded thoroly.

"**Seal Coat.** After the surface has been prepared as above, it shall be swept clean of all loose stone and an application of bituminous binder of approximately ⅓ to ½ gal, as directed, to the sq yd of surface area shall be applied evenly, which shall be covered immediately with a thin layer of dry stone chips and rolled lightly. The quantity of chips shall be sufficient to take up all excess bituminous material remaining on the surface. The finished surface shall conform with the grade and cross-sections.

"**Weather Conditions.** No bituminous materials shall be applied unless the stone surfacing is thoroly dry and the air temperature is at 18° C (65° F) or above."

Method C. The 1917 Ohio State Highway Dept. Specifications are as follows:

"**Sizes of Aggregate.** No. 1. Material passing thru a 3½-in and retained on a 2-in opening. No. 1 size for stone with an abrasion loss of greater than 6%, shall consist of material passing thru a 4-in and retained on a 2½-in opening.

No. 2. Material passing thru a $2\frac{1}{2}$-in and retained on a $1\frac{1}{2}$-in opening.

No. 3. Material passing thru a $1\frac{1}{2}$-in and retained on a $\frac{3}{4}$-in opening.

No. 4. Grit. Material passing thru a $\frac{3}{4}$-in and retained on a $\frac{1}{4}$-in opening.

No. 6. Grit. Material passing thru a $\frac{1}{2}$-in opening and retained on a $\frac{3}{16}$-in opening or square mesh.

No. 7. Screenings. Material passing thru a $\frac{1}{4}$-in opening or square mesh and containing not more than 30% of material that will pass a 100-mesh sieve."

"Size of Aggregate for Top Course. If the thickness of the completed top course is 3 in or less, No. 2 size aggregate shall be used. For courses over 3 in in depth, No. 1 size aggregate shall be used.

"Spreading Coarse Aggregate. Upon the foundation, prepared as elsewhere described, shall be spread a course of stone or slag, of sufficient depth to roll to the finished thickness shown on the plans. Cubical blocks of wood, or side and center guide forms of proper size, shall be used to fix the depth of the loose material. In spreading, care must be taken to preserve the grade and crown, and also to prevent a wavy surface. After the stone or slag is spread upon the foundation, it shall be harrowed to aid in producing a uniform and even surface. Any thin, flat or oversize stones that appear on the surface at any time during the process of construction, shall be removed therefrom. When spread, the material shall have a uniform distribution of sizes thruout the entire course.

"Rolling. The top course shall be rolled until it is thoroly compacted and the surface is smooth and conforms to the established grade and cross-section. The rolling shall begin with the outside driver covering equal parts of the metal and shoulder, and the roller shall be run forward and backward along the edge of the metal until the shoulder and metal are firmly bound together. The rolling shall then progress gradually from each side toward the center and this process repeated until the entire course has been thoroly rolled. Any low places that develop during the rolling shall be loosened and then refilled with the same kind of material as that of which this course is constructed, and again rolled, as required above.

"Partial Filling. Where this top course is to be thicker than 3 in, when completed, the bottom voids up to within 3 in of the surface shall be filled with dry No. 7 limestone or slag screenings or dry sand. The screenings shall be applied thinly over the surface during the process of dry rolling. The stone shall be so treated that the upper 3 in of the course will be free from all dust and fine material when the bituminous material is applied. During the finishing process of rolling any large voids in this course shall be partially filled with No. 3 stone which shall be whipped into the voids with shovels or by hand. Rolling shall be continued during the application of the stone. The voids in this top course shall be just sufficiently filled so that the amount of bituminous material specified will fill the remaining voids and produce a dense surface when the road is completed. Any dust remaining on the surface stone shall be removed by sprinkling with water. Sufficient time for the stone to dry shall elapse before any bituminous material is applied, but there shall be no more than 1000 ft of top course uncompleted at any one time.

"Applying Bituminous Material. No bituminous material shall be applied when the temperature of the atmosphere on the work is below 7° C (45° F) or when the stone is damp or wet. Without disturbing the stone or grit placed and rolled as above described, the bituminous material, of the quality specified in the estimate, shall be uniformly applied to the surface by means of approved pressure distributors or hand sprinkling pots. The total quantity of bituminous material used, including the seal coat, shall be as specified in the estimate. Immediately after the bituminous binder is applied, there shall be evenly spread over the entire surface, hard, clean, No. 4 grit of stone, slag or gravel in amount sufficient to fill the surface voids. The grit shall be evenly distributed with a push broom to insure the filling of the voids. It shall be so applied as to leave a minimum amount of grit on the surface. The road shall then be thoroly rolled before the bituminous material stiffens enough to prevent the grit from being readily incorporated with it. The rolling shall continue until a firm and smooth surface results, conforming to the requirements of the plans. Any surplus loose grit not held by the bituminous material shall be swept off and the surface kept clean until the seal coat is applied.

"Bituminous Seal Coat. After this rolling, not less than $\frac{1}{2}$ gal of the same bituminous material, heated as above, shall be uniformly spread over each square yard,

and the surface again covered with No. 4 or No. 6 grit at the rate of about 1 cu yd to 70 sq yd of surface. The road shall then be rolled until thoroly compacted. A sufficient amount of grit shall be left on the surface to protect the road while setting up."

Method D. The Road Board of England General Directions for Surfacing with Pitch-Grouted Macadam are as follows:

"1. Any road which is to be surfaced with pitch-grouted macadam should have a proper foundation or sub-crust of adequate thickness to bear the traffic likely to use it.

"2. Before laying a new surface of pitch-grouted macadam the thickness of the old crust, including foundations, should be ascertained by opening trial trenches at intervals averaging about 150 yd extending from the haunch of the road to the center, such trenches to be made alternately on opposite sides of the road.

"3. The thickness of the surface coating of pitch-grouted macadam when finished and consolidated by rolling should be 2½ to 3 in, except on very light traffic roads, when the thickness may be 2 in for single-pitch-grouting, and from 4 to 4½ in for the double-pitch-grouting hereafter described.

"4. In the case of naturally hard subsoils, not materially softened by infiltration of surface water, the total thickness of the road crust, including foundation, if any, after consolidation by rolling of the new pitch-grouted surface, should not under ordinary circumstances be less than 6 in, unless the subsoil is so hard as in itself to act as a good foundation, in which case the thickness of the road crust may be reduced to 4 in. In the case of clay or other yielding subsoils the total thickness should not be less than 11 in.

"5. The finished surface should have a cross-fall of about 1 in 32. If the crust is not sufficiently thick at the crown to enable this cross-fall to be obtained with a new coating of the thickness above mentioned, then the old surface should be left intact and unscarified, and the thickness of the new pitch-grouted coating increased as far as may be necessary. If the crust is of sufficient thickness for the purpose, the regulation of the cross-fall should be carried out by scarifying the surface and removing material from the crown to the sides previous to the application of the new coating. Material loosened by scarifying should be screened and all material finer than ½ in should be thrown aside.

"6. The aggregate of broken stone to form the new surface of pitch-grouted macadam should contain broken stone of approved quality of which at least 60% must be broken to the size of 2½ in, and 35% to sizes graded from 2½ to 1¼ in. In addition to this 5% of chippings of the same stone, varying from ¾ in down to ⅜ in, should be used for closing after the grouting with melted pitch.

"7. For making pitch-grouted macadam, the pitch used should comply with the Road Board Specification for Pitch (see Art. 8), its viscosity being altered to suit climatic and local conditions by varying the quantity of the tar oils as specified therein.

"8. It is important that the pitch should not be poured if the surface of the stone is wet. The stone may be protected by tarpaulins, or, if wet, may be dried *in situ* by portable blowers or other means.

"9. The quantity of pitch required to grout a single coating is approximately, for a consolidated thickness of 2 in, 1¼ gal per yd super, for 2½ in, 1½ gal per yd super, and for 3 in, 2 gal per yd super, but these quantities may vary with different materials and care must always be taken to fill the voids adequately.

"10. The aggregate after having been spread and levelled must be rolled down dry until the surface is formed, but without the addition of any small material.

"11. The pitch, after being carefully melted as described in Clause 18, must be raised to a temperature of 149° C (300° F). Clean, sharp sand must be heated on sand heaters to a temperature of 204° C (400° F). A dandy, or portable mixing vessel, is then to be filled with equal parts, by measurement, of the heated pitch and the hot sand, and the mixture, hereafter called the matrix, is to be kept well stirred, while it is being emptied from the dandy or portable mixing vessel into pouring cans of from 2 to 3 gal capacity, which are used for pouring the matrix on to the roadway. Not only during the process of mixing but afterwards, right up to the time of actual pouring, the matrix must be kept well stirred. The matrix prepared with pitch in the quantities specified in Clause 9 should be sufficient to fill the voids of the aggregate.

"12. The final rolling should be commenced immediately after pouring the pitch matrix, and carried on rapidly before the matrix has time to set. The 5% of graded chippings should be spread over the grouted surface in part previously to and the remainder during the process of rolling. The traffic may be allowed on to the finished surface as soon as the surface has cooled to the normal temperature.

"13. Double Pitch-Grouting. When the traffic is so heavy that a consolidated thickness of from 4 to 4½ in of pitch-grouted macadam is required, it is desirable, in order to obtain the best and most economical results, to divide the coating into two layers, the bottom layer to be the thicker one and to consist of large stones, the two layers being rolled down and grouted separately. Any local stone which can be procured cheaply may, if suitable in quality for foundation work, be used for the bottom layer graded from 3-in gauge down to 2-in gauge. No chippings are required for finishing the rolling of the bottom layer. The aggregate for the upper layer should consist of hard road stone of approved wearing quality, broken to 1½-in gauge, and 5% of chippings of the same stone used for the upper layer, graded from ½-inch down to ¼-in, should be added before and during the process of rolling, and rolled down so as to form the finished surface of the road.

"14. In pouring the pitch on the bottom layer the surface of the pitch should not be brought to the surface of the stone, but should lie about ½ in below such surface, with the object of providing a key for the upper layer.

"15. The materials and the methods of grouting and laying down in the case of double-pitch-grouting, should, except when otherwise expressly stated, conform to the provisions of Clauses 7, 8, 10, 11 and 12.

"16. The quantity of pitch required for double-pitch-grouting is approximately, for a consolidated thickness of 4 in, 3¼ gal per yd super, and for 4½ in, 3½ gal per yd super, but these quantities may vary with different materials, and care must always be taken to fill the voids in the surface coating adequately.

"17. For the purpose of accurately ascertaining the proportions necessary for the matrix, it is essential that portable weights, scales and measures be provided, and all materials used in the preparation of the matrix should be accurately proportioned by weight or measurement.

"18. Instructions for Melting the Pitch. The pitch boilers of from 2 to 3 tons capacity should be charged with pitch and about one-half of the proper proportion of tar oils. The fire should then be lighted, and thereafter a steady fire, with fire doors closed, should be maintained, when, in from 4 to 5 hr, the pitch should be thoroly melted. A bright fire should be kept until the pitch reaches a temperature of 149° C (300° F), when the remainder of the oils should be added and the mixture thoroly stirred; the fire-doors should then be opened and the temperature of the melted pitch permitted to fall to 121° or 132° C (250° or 270° F). The pitch should then be ready for use and in all cases should be thoroly well stirred before being drawn off. In the event of bad weather stopping the work of grouting the fire-door should be left open, the damper closed, and the temperature of the pitch allowed to fall to 93° C (200° F). It can be kept at this temperature for long periods with banked fires consuming about 7 lb of coke per hr. It is recommended that a suitable Fahrenheit thermometer with metal protection should be at hand to indicate the temperature of the melted pitch. Whenever the weather is favorable for the recommencement of the work the pitch must be again raised to 132° C (270° F) by closing the doors and sharp firing. It is desirable that the boiler should be kept air-tight when the pitch is being melted, by the use of air-tight covers properly packed so as to make an air-tight joint."

Method D. The Mass. Highway Comm. Specifications (24) are as follows:

"Upon the lower course shall be spread the upper course of stone, which shall consist of broken trap rock that will pass thru a ring 2½ in in diameter and will not pass thru a ring 1¼ in in diameter, and shall be 2 in in thickness after rolling with a steam roller, and evened up with material of the same size and quality as has been used in that particular course and to the satisfaction of the Engineer.

"Upon and into the interstices of the upper course, prepared as hereinbefore described, shall be broomed and poured hot tar and hot sand at the rate of 2½ gal per sq yd.

"The proportions of sand and tar in the mixture shall be equal in volume, that is, the mixture shall consist of 50% hot sand and 50% hot tar. The sand shall be clean and sharp and free from loam, clay and adventitious matter of all kinds. The grains of sand shall pass thru a 16-mesh sieve, not more than 20% shall pass a 100-mesh sieve, not more than 5% shall pass a 200-mesh sieve. The sand shall be heated in a manner satisfactory to the Engineer to approximately 149° C (300° F), and after heating, the sand shall be mixed immediately with the tar, in such manner as to be satisfactory to the Engineer, and so handled that when it is poured into the road, the sand will not have settled to the bottom of the tar, but shall be in complete suspension. Before mixing, the tar shall have been heated to a temperature approximately 107° C (225° F).

"Immediately after the tar and sand mixture has been broomed and poured into the top course the surface shall be covered with a thin layer of pea stone and immediately rolled with a steam roller weighing not less than 10 tons, to the satisfaction of the Engineer."

Method E. Specifications Based upon American Practice.

Base Course. The lower course shall consist of crushed stone which shall pass a 3½-in ring and be retained on a 2¼-in ring, spread to a finished depth of 4 in, but 2½ in below the finished grade. The course shall be filled thoroly with sharp sand, gravel, stone screenings or similar filler approved by the engineer, and rolled until smooth and firm. No filler shall be left on the surface.

Sand Layer. On this course of stone thus prepared, shall be spread evenly a layer of sharp sand to the depth of not less than ¾ in, nor more than 1 in.

First Coat Tar. Refined tar, heated to a temperature of not less than 93° C (200° F) and not more than 135° C (275° F), shall then be spread evenly over the surface to the amount of not less than 1 gal, nor more than 1¼ gal per sq yd.

Wearing Course. The wearing course shall be placed on the tar mortar and shall consist of a layer of crushed stone which shall pass a 2¼-in screen and be retained on a 1¼-in screen spread to a finished depth of not less than 2½ in. This size of stone is best for trap rock or other hard rock which does not break under the roller. If limestone or other soft rock is used a larger sized stone may be used to advantage. This course shall not be filled, but shall be keyed thoroly together by rolling. The surface shall be left smooth and of even firm texture clean and free from dirt, clay, stone dust or other material which will prevent the easy penetration of the refined tar.

Second Coat Tar. Refined tar, heated to a temperature of not less than 93° C (200° F) and not more than 135° C (275° F) shall be spread uniformly over the surface when dry to the amount of not less than 1½ gal, nor more than 1¾ gal per sq yd.

Three-Fourths Inch Stone. As soon as possible after spreading the refined tar ¾-in crushed stone without dust, stone which shall pass a 1¼-in screen and be retained on a ½-in screen, shall be spread over the surface filling the voids, but leaving no surplus on the surface. The road shall then be rolled until firm.

Seal Coat. The road shall be swept free from any particles of stone not held by the tar. Not less than ½ nor more than ¾ gal of refined tar per sq yd, heated to a temperature of not less than 93° C (200° F) nor more than 135° C (275° F), shall be spread over the surface and covered with stone screenings or sharp sand. The road shall then be rolled until compacted. A sufficient amount of screenings or sand shall be left on the surface to protect the road while setting up.

Method F. The 1917 Specifications of the Ill. State Highway Dept. are as follows:

"**Tests and Sizes of Crushed Stone.** Crushed stone should be of sound and durable material, and shall have a coefficient of wear according to the Duval test of not less than 7. The sizes of crushed stone that shall be used are as follows:

1. Uniformly graded and broken to a size that will pass over a 2-in ring and will just pass thru a 3-in ring, which size will hereinafter be referred to as 3-in stone.

2. Uniformly graded and broken to a size that will pass over a ¼-in square mesh and will just pass thru a ½-in ring, which size will hereinafter be referred to as chips. This stone shall be clean and entirely free from dust.

3. Uniformly graded and broken to a size that will just pass thru a ½-in ring and be uniformly graded to dust. This material will hereinafter be referred to as screenings.

" **Spreading First Course of Stone.** The first course of stone shall be of 3-in stone, spread to compact under rolling to the dimensions shown on the plans. The stone may be dumped directly upon the roadbed, but in such case it shall be distributed uniformly over the foundation.

" **Harrowing First Course of Stone.** After the first course of stone has been spread, it shall be thoroly harrowed several times over until a maximum density is obtained and all fine material which may have been mixed with 3-in stone has been shaken to the bottom of the layer. The harrow shall be of the stiff tooth type and shall have metal teeth at least 1 in in diameter extending 6 in below the harrow frame. The spacing of the teeth shall be such as to admit the free passage of all stone between them, and yet so displace the stone as to produce the density desired. The design of the harrow shall provide a weight of from 8 to 12 lb upon each tooth.

" **Rolling First Course of Stone.** After the stone for the first course has been spread to the required depth, harrowed, and then shaped to the proper cross-section, it shall be rolled until the entire surface is covered and thoroly compacted, forming a firm smooth surface. The rolling shall begin at the sides and work toward the center, at each rolling allowing an overlap of one-half of the width of one of the rear wheels, and these wheels shall cover the entire metal surface thoroly. The speed of the roller shall not exceed 100 ft per min. If any unevenness or depressions appear during or after rolling, material shall be added and rolled until there has been formed a thoroly compacted and uniform surface.

" **Spreading Screenings, Watering and Rolling.** After the first course of stone has been properly shaped and rolled to the satisfaction of the engineer, the screenings, or bonding gravel, shall be applied in several successive layers and the surface broomed and rolled between each application until the voids in the stone are practically filled with dry screenings. Screenings shall be spread uniformly over the surface of the road from piles along the side, and in no case shall screenings be dumped directly upon the surface of the stone. After the voids have been filled with screenings, the surface shall be sprinkled until saturated, the sprinkler being followed by the roller, and more screenings shall be added, if necessary. The sprinkling, sweeping and rolling shall continue until a grout has been formed that will fill all of the voids and will form a wave of water and grout before the wheels of the roller. The entire operation of spreading screenings, watering and rolling shall be done to the satisfaction of the engineer.

" **Spreading and Harrowing Second Course of Stone.** The stone for the second course shall not be spread until the foundation or first course has been completed and shoulders made as herein specified. The second course shall be of 3-in stone, and shall be spread to compact under rolling to the dimensions shown on the plans. After the second course has been spread it shall be harrowed as hereinbefore specified for the first course of stone.

" **Rolling Second Course of Stone.** After the stone for the second course has been spread to the required depth, harrowed and shaped to the proper cross-section, it shall be rolled until it is compacted and forms a firm, smooth surface. The rolling shall begin at the sides of the pavement and work toward the center, and, when completed, the surface of the shoulders, and of the second course, shall be smooth and true to the cross-section shown on the plans. If any unevenness or depressions appear during or after rolling the second course, either on the surface of the shoulders or stone, material shall be removed, or additional material shall be added to correct all such unevenness or depressions, and the entire surface rolled until it becomes smooth and uniform in character.

" **Spreading First Coat of Bituminous Binder.** After the surface has been prepared as described above and it is dry and free from dust, the bituminous binder heretofore specified shall be uniformly distributed at the approximate rate of 1½ gal per sq yd of surface. It shall be spread at the temperature hereinbefore prescribed and in a manner which will insure a uniform appearance to all parts of the surface. If the surface of the road is open and the stones are not tightly keyed after rolling as prescribed above, the surface voids shall be partially filled with chips before the bituminous binder is applied.

" **Spreading First Course of Chips.** After the first course of bituminous binder has been applied, the surface voids shall be filled with chips which shall be whipped into the

surface from shovels, the quantity being such as will just fill the surface voids. After the chips have been whipped and broomed into the surface and all surface voids filled, the excess material remaining on the surface shall be swept off the pavement and the surface rolled once over with the roller.

"**Spreading Second Coat of Bituminous Binder.** After the first course of chips has been spread and brushed into the surface and rolled slightly, a second coat of the bituminous binder shall be spread at the approximate rate of ⅓ gal per sq yd of surface. The binder shall be applied hot and in such manner as will insure a uniform appearance of the surface.

"**Spreading Second Course of Chips or Torpedo Gravel.** After the second coat of bituminous binder has been applied, there shall be spread a thin course of chips or torpedo gravel which shall be brushed into the surface. If after these voids are filled, there is any excess of stone chips or torpedo gravel on the surface, it shall be brushed to the edge of the pavement. The surface shall then be rolled until it is entirely free from depressions, waves, etc, the wheels being wet to prevent sticking. After the surface has been rolled, it shall be allowed to stand for at least ½ day before being open to traffic. After being open to traffic, if during the first 30 days the bituminous binder exudes on any part of the surface, such places shall be covered with torpedo gravel or chips in a sufficient quantity to absorb the excess binder."

Method G. 1917 Specifications of Oakland, Cal. For sections covering broken stone, see Art. 6; for sections covering the asphaltic oil employed, see Art. 8.

"**Wearing Course.** Upon the base course shall be spread a course of broken stone, to be known herein as the top course, having a uniform depth of 3 in, measured before rolling. This top course shall then be sprinkled uniformly with oil at the rate of ½ gal per sq yd of street surface covered, after which said top course shall be harrowed and again sprinkled uniformly with oil at the rate of ½ gal per yd of surface covered. This oiled surface shall then be thoroly rolled until said top course is firm and uniform, screenings being spread in light layers on said top course during the rolling. After the top course has been so prepared, oil shall be sprinkled uniformly over the surface at the rate of ½ gal per sq yd of street surface covered. This oil shall be permitted to penetrate into the top course, after which the roadway shall be screened and rolled and swept until the voids are filled and the pavement is firm and uniform. The pavement shall then be treated with another application of oil at the rate of ½ gal per sq yd, then screened, rolled and swept until all of the oil has been absorbed and the surface is uniform and firm.

"**The Rolling** herein specified shall be done with a self-propelled roller weighing at least 300 lb per lin in width of tread. In all of the hereinabove mentioned rolling, the sides of the roadway shall be rolled first, the roller gradually working toward the center of the roadway.

"Oil shall be applied to the pavement under pressure of at least 30 lb per sq in. The appliance used for said oiling shall be capable of spraying the pavement in strips at least 8 ft wide and shall, in addition to being provided with the necessary nozzles for spraying such strips, be also provided with a hose, with spraying nozzle attached thereto, for the purpose of spraying portions of the pavement inaccessible to the regular oiling device. All oil must be delivered at the point required for sprinkling at a temperature of not less than 121° C (250° F). All of the above-mentioned oiling shall be done while the atmospheric temperature is above 18° C (65° F), or when the sun is shining. No oiling shall be permitted when the layer of broken stone or the screenings are in any way wet."

12. Construction Cost Data

The cost of bituminous pavements, built by penetration methods, varies with the amount and kind of bituminous material and road metal used, and the method of construction employed. An average cost, using 6 in of compacted broken stone and a total of 2 to 2¾ gal of bituminous material per sq yd, varies from 25 to 40 cents per sq yd in excess of the cost of water-bound broken stone roads, or from 70 cents to $1.25 per sq yd.

Table I.—Cost of Bituminous Macadam Pavements in 1915 in Several Cities

From *Engineering and Contracting,* April 5, 1916

City	Square Yards	Price* per Square Yard	Total Thickness Inches	Kind of Binder
Bennington, Vt....	1 280	$0.70	6	Asphalt
Boston, Mass......	177 093	0.75	6	Tar
Springfield, Mass...	95 907	0.89†	6	Tar
Providence, R. I...	18 012	1.27	8 2/8	Tar
Oswego, N. Y......	15 832	1.58	8	Asphalt
Pittsburgh, Pa.....	8 920	1.55	9 1/2	Tar
Cincinnati, O......	5 106	1.15	9	Tar
Toledo, O..........	5 489	1.40	10	Tar
Chicago, Ill.......	598 254	1.21†	10 1/2	Asphalt
Milwaukee, Wis...	8 890	1.08†	8 1/2	Tar
St. Paul, Minn....	3 600	1.25	7	Tar
Springfield, Mo....	9 966	1.06	6	Asphalt
Durham, N. C.....	20 900	0.90†	6	Asphalt
Covington, Ky....	15 000	1.20	10	Tar
Fort Worth, Tex...	5 267	1.27	6	Asphalt
Riverside, Cal.....	36 850	0.78	4	Asphalt

*Price covers pavement, foundation, and grading.
†Does not include grading.

Bituminous Macadam Pavement Cost Data by Ill. Highway Comm. (40b). Length, 1500 ft; area, 3500 sq yd; thickness, 3 in; labor, 25 cents per hr; teams, 50 cents per hr; average haul, 1/2 mile; bituminous binder, 2.54 gal per sq yd; constructed, Sept. 29 to Nov. 25, 1915.

Bituminous Macadam Pavement Constructed with Pouring Cans, Alexandria, Va. Cost Data compiled by E. C. Dunn, City Engineer (28). For description of method of construction, see Art. 9. "The cost for an average square yard exclusive of grading was $1.01 in 1915 and $1.135 in 1916, the difference being due to increased cost of material in 1916. The details of the average cost per square yard in 1916 were as follows:

Cost of Labor and Materials

	Per square yard
Superintendence and inspection	$0.077
Cost of stone and gravel	0.430
Cost of sand and chips	0.085
Cost of bituminous binder	0.217
Hauling stone, gravel and chips	0.210
Spreading stone and screenings	0.058
Rolling and sprinkling	0.039
Heating and applying bituminous binder	0.060
Incidental expense	0.019
Total cost	$1.195

Concrete Base

	Cents	Cents
Materials:		
Water	0.25	
Sand delivered 165 lb at 1/2 cent	8.25	
Cinders, on cars, 1/7 cu yd at 16 2/3 cents	2.38	
Cement, on cars, 11/100 bbl at $1.47	16.17	
Tools, etc	1.00	28.05
Labor:		
On concrete and placing 50 lb stone	13.00	
Teams	4.00	
Supervision	0.50	17.50
Total cost of concrete base		45.55

Top Wearing Surface

Material:	Cents	Cents
Stone 350 lb trap on cars at 0.69 cents	24.15	
Asphalt, 2½ gal on cars at 8.4 cents	21.00	
Fuel	0.80	
Tools, etc	2.00	47.95
Labor:		
Men	12.50	
Teams	6.00	
Supervision	1.50	20.00
Total cost of top wearing surface		67.95

Total cost of concrete base and wearing course per square yard, $1.135.

Wages: Foreman, 25 cents per hr; laborers, 17 to 18 cents; carts, 30 cents, and double teams, 40 cents per hr; haul, 0.95 mile, average. Work done by day labor, City Engineer's wages not included."

Bituminous Gravel Pavement, Longview, Texas. According to Green (37), the cost of constructing the bituminous gravel pavement described in Art. 9 was $1.40 per sq yd complete, details being given in Table II:

Table II

Quantities	Grading, Including Rolling, 1200 Cu Yd	Curb, Wood, 2 by 12 In 1915 Lin Ft	Foundations, 8 In Loose, 785 Cu Yd	Top Coat, Gravel, 404.3 Cu Yd	Asphalt 3872 Sq Yd
Cost:					
Labor	$587.130	$141.160	$434.010	$629.080	$346.960
Labor, per unit	0.489	0.074	0.112	0.162	0.090
Material	....	95.080	1393.600	888.580	1111.250
Material, per unit	....	0.050	0.360	0.230	0.287
Total	$587.130	$236.240	$1827.610	$1517.660	$1458.210
Total, per unit	0.489	0.124	0.482	0.392	0.377

Wages: Foreman, $5.50; engineer, $5 and $3.50; timekeeper, $3; water boy, $1; skilled labor, $2.50; labor, $1.75; teams, $4. Materials: Crushed rock, $1.50 per cu yd; gravel and sand, $1.87 per cu yd; asphalt, $20 per ton; lumber, $10 per M.

MAINTENANCE

13. Causes of Failure

The causes of failure of bituminous macadam and bituminous gravel pavements may be considered under the following heads, bituminous material and methods of construction.

Bituminous Material. Unfortunately many are the instances where unsuitable bituminous materials have been employed. Many engineers having charge of bituminous work do not appreciate the fact that different types of bituminous materials have entirely different physical properties and require entirely different treatment in use, altho they may have been purchased under one and the same specification covering chemical and physical properties. In some cases entirely unjustifiable combinations of materials are employed. For instance, in one case an asphalt of excellent characteristics was used for the first application, while for the second

application an asphaltic oil having decidedly solvent and fluxing properties was employed. Overheating of the material has likewise proved the cause of many failures, as the properties of the materials are sometimes changed and in many cases the materials are ruined.

Methods of Construction. Failure of the wearing course usually results if the foundation is poorly constructed or is inherently deficient in the strength required to carry the traffic to which the roadway is subjected, or if the sub-drainage is poor. Insufficient rolling of the wearing course has caused many failures. Others are due to the uneven distribution of the bituminous material, frequently caused by the improper use of hand-pouring pots and hand-drawn distributors. Many unsatisfactory bituminous macadam pavements result from the use of the improper sizes of broken stone. The use of small sizes of soft stone, which has crushed under heavy rolling, has resulted in a closed surface, thus preventing the necessary penetration of the binder. Failures due to the rapid formation of fine cracks caused by the rocking movement of the individual stones under traffic, finally resulting in ravelling and general disintegration, are of common occurrence. Segregation of sizes of stone preventing uniform penetration results in lean or weak spots in some cases and fat spots in others. In certain cases after a rain the construction has been carried on before the broken stone immediately below the surface has dried out. Many of the causes attributed to the failures of bituminous surfaces may likewise apply to bituminous macadam and bituminous gravel pavements.

Failures Due to Subgrade Conditions by Patterson (42). "A penetration pavement is more susceptible to failure by reason of subgrade troubles than are many other pavements. The reason for this susceptibility is explained in many ways, but it seems logical to attribute it to the inability of the pavement to withstand upward pressure locally applied by frost action and to the unavoidable large percentage of voids which have a weakening effect. Penetration work gives the best results when laid over a freely permeable soil. Sand and gravel are ideal sub-soils. A heavy soil of low permeability is as a rule disastrous to penetration work in New England latitudes unless special precautions are taken. In Rhode Island state work, an insulating layer of sand or gravel beneath the pavement is always employed where the existing soil lacks the requisite degree of permeability. A fill of wall or field stone is substituted for the gravel or sand where sub-drainage and foundations are both required. Drainage of certain soils is not as a rule sufficient in penetration work. Replacing of undesirable soils for a depth of from 6 in to 2 ft below the pavement proper with sand or gravel appears to be the most satisfactory method."

14. Methods of Maintenance

General Considerations. The maintenance of many bituminous macadam pavements requires covering spots with sand, gravel, or stone chips, where either an uneven distribution or an uneven penetration has caused an excess of bituminous material to exude on the surface. Places which disintegrate should be cut out with perpendicular sides and refilled with either a mixed aggregate or by building the hole up with successive layers of road metal and bituminous material, the former method, however, giving the better results. Light oils and light tars should never be used for repairing holes, as the patches thus formed will not be stable and hence will soon be displaced by traffic. At varied intervals it is economical to renew the bituminous surface on the pavement by using from ¼ to ¾ gal per sq yd of the proper type of bituminous material.

Continuous Maintenance Methods and Equipment. In considering the equipment required to accomplish continuous maintenance of bituminous

macadam pavements, the following factors and principles are essentials of economical and satisfactory maintenance.

1. Small failures of the wearing course, and the wearing away of the bituminous surface on comparatively small areas should be repaired immediately. Otherwise the rate of disintegration will be materially increased, the annual maintenance charge will be greater than necessary, and the surface will be unsatisfactory to the users of the highway.

2. Continuous maintenance should be conducted so that the highway may be at once opened to traffic without injury resulting to the repaired sections. For the repair of pot-holes, ruts, and other holes or depressions, this implies the use of bituminous materials which will set up more quickly than those which have been used in many cases. If practicable, the same type and grade of bituminous binder should be used as was employed in the original construction.

3. In order to obtain satisfactory results, the labor should be efficient and should be under the supervision of an engineer experienced in the construction and maintenance of all types of highways, and with all kinds of bituminous materials used in the area under his jurisdiction.

4. The intimate relationship between the methods and materials used in construction and the character of the maintenance is such that, to ensure success, the construction and maintenance of highways in a unit of area, or a certain mileage, should be under the supervision of one engineer.

To accomplish continuous maintenance economically and efficiently under the foregoing conditions, the flying squadron, operated under the direction of an engineer in charge of construction and maintenance of highways in the area covered, appears to be the logical solution. The equipment of such a squadron will naturally depend on local conditions, such as the mileage of highways to be maintained, their relative location, the types of surfaces and pavements, the kinds of bituminous materials used, the mileage under guaranty, etc.

As an example of a definite problem in continuous maintenance, take a county or a division of a State where a considerable mileage of bituminous surfaces and bituminous pavements has been constructed. Granted a well-maintained system, the work to be accomplished by a flying squadron would consist, first, of routine repairs, including filling all holes, ruts, and other depressions with bituminous concrete, using a type of aggregate and bituminous material suitable to each case (see Sect. 16, Art. 23), and second, applying bituminous materials to all areas which gave indication of being in such condition that they should be re-treated at once rather than wait until the whole surface required another application. It will be practicable in many cases for the flying squadron to repaint guard-rails and perform other routine repair work. Under such conditions, it is believed that the use of a motor truck properly equipped will prove most satisfactory.

The equipment to be carried by the motor truck for the special repair work outlined should include the following machinery and supplies: A stone heater and mixer; two heating tanks; a surface heater; a hand roller; small barrels of bituminous materials of different types and grades; storage boxes of small tools such as brushes, squeegees, tampers, cutters, pouring cans, irons, shovels, picks, and hoes; and storage compartments for paints for guard-rails, and road metal of several sizes. Altho a storage capacity for road metal is called for in this equipment, it should be noted that only a few cubic feet will be carried, because the maintenance work performed will be confined to the repair of small patches. Usually, it will be practicable to

reload a truck each day. The fixtures for the equipment described should be arranged so as to be readily removed, thus allowing the truck to be utilized for general hauling purposes.

The equipment recommended herein could be carried by a 5-ton truck, capable of traveling 12 miles per hr, and having a gasoline storage capacity for a run of 100 miles. A clear body of 7 by 15 ft would be available for the installation of the equipment. The cost of operation under normal conditions during an 8-hr day would vary from $10 to $20, covering wages of chauffeur, rent of garage, interest on first cost, maintenance charges, depreciation, insurance, tires, gasoline, oil, and grease.

Conclusions on Suitable Bituminous Materials for Maintenance by Sharples (16d). "In building country roads, it has been the practice in many cases to construct a tar-bound macadam road, and coat it with one of the heavy asphaltic oils or light asphalts put on hot. This practice has given excellent results in many cases, and has been established as a standard specification in some states, notably in Connecticut. Some very good work has been done in this way. In carrying out work under a specification of this kind, it is very important that the grade of oil or oil-asphalt be so heavy that it will not penetrate the tar-bound macadam, but will stay on top as a blanket layer. An oil light enough to penetrate the tar-bound road is sure to give bad results. The speaker knows of a number of roads of this type, which were well built and then treated with a light oil, while still presenting a porous top. They disintegrated completely within a year when subjected to heavy horse-drawn traffic, altho neighboring sections sealed with tar products remained in good condition. If, however, a proper grade of asphaltic oil is used, this disintegration will not occur.

"Under city or town traffic conditions, the tendency of an oil-asphalt top over a tar-bound macadam is to mush up and become soft under horse-drawn traffic in wet weather, due to the emulsifying effect of the water and organic material which collects on the asphalt top. When these conditions are to be provided for it is important so far as present experience indicates, to use only tar seal coats on top of the tar-bound macadam. The refined tars used for the seal coats are preferably somewhat softer than the tar used in the tar-bound macadam, but the subsequent treatment and care of the road modifies somewhat the character of the seal coat required. For maintenance within city and town limits, where the horse-drawn traffic is considerable, it has been found that a specially prepared tar, which can be applied cold, gives much better results than the heavier tar materials put on hot.

"Consider the light dust-laying oils and their effect on tar-bound macadam. It is a problem which affects city and town conditions. In country practice, the conditions do not arise where an oil of this type is necessary. On city and town streets, a troublesome dust often collects, which the ordinary seal coat of tar or heavy asphalt does not keep down. In applying a light oil over a tar-bound macadam to keep down this superficial dust, it is essential to comply with certain conditions if the tar-bound macadam is not to be ruined. It is the utmost folly to put a light oil on a tar-bound macadam; if there is the least chance for the oil to penetrate the macadam, the results are sure to be disastrous. The tar-bound macadam will be disintegrated. A light oil has two effects on the tar-bound macadam. It has a chemical effect on the tar which causes its disintegration and makes it lose its binding force. It also has a physical effect on the macadam structure. The oil is a lubricant; and if there is any stone loose enough to move in the tar macadam, the light oil accelerates the movement, and a hole is sure to develop. This dual action of the light oil can be observed in many large cities at the present time, and many streets may be seen which have been built with tar-bound macadam, the life of which has been gradually shortened by the use of light oil. The effects of the light oil can be minimized if the tar-bound macadam is thoroly sealed, either thru an excess of bituminous material in the first place, or by subsequent applications of refined tar. Certain precautions must be taken also in applying the oil. An excess of oil should never be used, and it should be applied to the surface only in sufficient quantity to take up the loose dust which is found there. A very small fraction of a gallon is sufficient. If more than this is applied, the oil gradually sinks into the tar-bound macadam and in the end will rot it."

Mass. Highway Comm. Practice, as described by Dean (16d). "If slight depres-

sions or small holes occur, they are usually due to imperfections in construction and may be repaired by painting with bituminous material and filling with chips or pea stone, or they may be filled with bituminous coated stone, and tamped or rolled. Traffic and climate govern the demands for more extensive maintenance. With moderate traffic, perfection of surface is maintained by spraying the surface about once in 2 years with a lighter grade of tar or asphalt. The process consists in sweeping thoroly the surface, spraying at the rate of about ¼ to ⅜ gal per sq yd, and covering with pea stone. If the surface becomes worn too much for such treatment, it may be restored by lightly scarifying, smoothing by rakes or harrow, adding more stone and rolling it into place, and then following the methods used for new construction. This last method of resurfacing, provided the road foundation was originally properly constructed, may be subsequently repeated as often as necessary, thereby utilizing the permanent base and first course and maintaining a semi-permanent surface good for any except extremely heavy vehicles."

Penn. State Highway Dept. Practice by Biles (19), giving reasons for, and methods of repairing.

"1. A section of road where the surface is composed of spots of excess bituminous material and bare or lean areas where the binder is lacking in quantity, which condition results in a short time in a raveling or breaking up of the road surface. This condition is usually caused by improper distribution or by incorporating the bituminous material when the stone is not thoroly dry. The first case, if taken in time, can be repaired by sealing the dry or lean spots in the surface with a light, heated application of bituminous cement of the binder grade, or the cold bituminous surface treatment materials in quantities ranging from 0.1 to 0.3 gal per sq yd of surface, covered with chips or pea gravel, using between 15 and 20 lb per sq yd. Unless the surface is worn badly, repairs of this character will even up the surface to a true cross-section, giving added life to the pavement.

"2. A rough surface is presented where the stone is loosened or raveled, the binder showing rapid deterioration, generally causing a series of pot-holes. This may be occasioned by improper or overheated bituminous material, unsatisfactory aggregate or faulty sub-drainage. The second condition calls for heroic treatment, if of any great extent, and a complete scarifying and harrowing of the surface becomes necessary. All disintegrated material must be removed and sufficient new stone added to give the required depth before the surface can be repenetrated and sealed as in the original construction. If, however, the affected portions are only occasional and do not represent the greater area, they may be cut out, cleaned thoroly and filled with new stone, making due allowance for compression, then penetrated, etc, in the manner hereinbefore mentioned. If drainage conditions are responsible for the failure they must be corrected before any surface repairs are taken up.

"3. At times there is apparently a lifeless surface in so far as the bitumen is concerned, but upon further examination it is found to contain bituminous binder with considerable life a slight depth below the surface. This condition is due in many cases to an insufficiency of bituminous material. The condition described in the third example may be treated in two ways. The most economical so far as first cost is concerned would be to give the pavement a treatment, in sufficient quantity to fill the surface voids, with a material that will penetrate and enliven the old material, followed by a covering of good, hard stone chips, using about 20 lb per sq yd. The alternative would be to scarify and harrow the whole surface, supplying additional new stone in quantities as the rolling would indicate to be required to give the proper cross-section, and penetrating the surface with a bituminous binder, sealing again as in the original construction. In the latter method, the surface must first be thoroly cleaned, and in scarifying and harrowing, the remaining bituminous material in the road must be distributed as evenly as possible. If the material found in the pavement, however, does not possess life, this method is a hazard.

"4. A pavement may present a wavy and uneven appearance and this is usually due to an excess of bituminous material or is caused by the bituminous material being too soft to withstand the action of traffic. In the wavy, corrugated surface, where there is found to be an excess of bituminous material, it is generally more economical and satisfactory to scarify and reshape the surface, adding new stone in order to take up the excess bitumen, and again sealing the surface. This same method should be followed where waves have been caused by the bituminous material being too soft, only perhaps

more stone would be required in the reconstruction and it would be essential to incorporate a harder bituminous binder than was used in the original construction. Occasional waves in the surface may be taken out in the due course of ordinary repairs by cutting off the high places and resealing, if the conditions are very pronounced or by cutting out the depressions and replacing with new material.

"5. There are surfaces which consist of ridges of material which are the result of irregular or improper pouring; in most cases, careless hand pouring. A surface of this kind suffers quickly from the impact of traffic and the attack of the elements, and early disintegration is the result. A surface full of ridges due to improper pouring, if not too pronounced, may be evened up by painting between the ridges with bituminous cement and covering with stone chips or gravel. This method may be continued from time to time until the surface is entirely evened up. This condition may also be corrected by scarifying the surface with the object of obtaining a more uniform distribution of the old bituminous material and, after rolling to the proper shape, by applying a surface treatment of a cold bituminous material that will enliven the existing material and seal the surface. This treatment is covered with stone chips in the manner prescribed for regular bituminous surface treatment work.

"6. The case of a fairly well-shaped, uniform surface becoming porous. This condition is true of all bituminous highways in time, as it represents the beginning of the deterioration of the bituminous material. In the last case there is a properly constructed bituminous penetration pavement, but the bituminous material is starting to deteriorate. This can be enlivened or revived by cleaning the surface and applying a seal coat of material in quantities depending upon the degree of disintegration. Caution should be exercised to avoid applying an excess amount, which results in a slippery condition and is very objectionable to horse-drawn traffic. Generally 0.1 to 0.2 gal is used and brushed into the surface with hand brooms. The surface is then covered with chips or gravel approximating 20 lb per sq yd. In the use of certain slow drying cold bituminous materials it will be observed that the new material softens up the old bitumen somewhat, giving the appearance at first of an excess application, and, having a hard surface underneath, the road becomes quite slippery, but this condition obtains for only a short period of time. To insure the best results, one-half of the road should be treated at a time in order that the traffic may use the other portion while the bituminous material is setting up. This method has become quite effective and results in increased life to the pavement.

"In the repair of breaks, depressions and local defects, which may occur under any one of the general conditions previously outlined, it is more satisfactory to use hot bituminous binders, and if replacements are necessary they can be made after the fashion of the original construction. This work can be done very efficiently in this manner with little equipment and the average class of labor. There are a number of instances where cold bituminous compounds can and are being used successfully in certain seasons of the year on pavements of this kind, but in cold weather there is usually difficulty with some of this material, owing to its composition. As an example, the emulsified products break down or separate and their adhesiveness is destroyed at low temperatures. Materials that are cut-back with natural solvents can be used later and give very good results. The mixtures can be prepared at some point, not exposed to the weather, but convenient to the work, hauled to the site of the repairs, and deposited. This is an effective method in case of emergency."

N. Y. State Highway Comm. Practice by Sturdevant (16d). "In order to keep the surface of a road in smooth, proper condition, it should be under constant surveillance, and receive constant attention. As the surface becomes worn in places, and holes and ruts develop, they should be repaired at once, for if neglected they rapidly extend in size and depth under the action of each traveling vehicle. On bituminous surfaces, the best results are obtained, if the asphaltic materials are first mixed with stone, gravel, or other suitable ingredients. This mixing can be done at any time, and in sufficient quantities to last for several months, for the weather will not cause the mixed material to deteriorate. The writer has used material which had been mixed during the previous summer and piled by the roadside, and has obtained as good results as with fresh materials. In all patching work, the first requisite is to see that the surface to be repaired is well cleaned before new material is placed; also, in repairing holes and ruts, care must be taken not to use too much asphaltic material, and it is well not to have the new patch flush with the surface, for, under the action of the sun, the

asphalt, whether light or heavy, will come to the surface. Then the patch will become sticky and is likely to be pulled off by heavy slow-going vehicles. To prevent this, more stone and fine material must be used as covering, and if too much was used originally, a hump will develop which is as disagreeable as the original rut or hole. This is not as likely to occur when the material has been mixed before placing, as when the asphalt is placed first and then covered."

Maintenance Cost Data in Portland, Me., by Hunt (39). The data given in the following table pertains to a section of bituminous macadam 2879 ft in length, located on Danforth and Vaughan Sts., between St. John and Bowdoin Sts., constructed in 1908 at a cost of $1.18 per sq yd.

Date	Repairs	Surface Treatment	Total Maintenance	Maintenance per Sq Yd
1908.............	....	......	....	....
1909.............	$ 90.00	......	$ 90.00	$0.0104
1910.............	293.12	306.88	600.00	0.0691
1911.............	69.50	246.04	315.54	0.0363
1912.............	72.38	157.77	230.15	0.0266
1913.............	95.76	96.96	192.72	0.0223
1914.............	98.13	100.58	198.71	0.0229
1915.............	60.87	126.90	187.77	0.0217
1916.............	105.72	......	105.72	0.0122

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SECTION 16

BITUMINOUS CONCRETE PAVEMENTS

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GENERAL DATA

1. Definitions, Classification and Patent Litigation

Definition Adopted by Spec. Com. Mat. Road Cons., Am. Soc. C. E. (17e). "A bituminous concrete is one composed of broken stone, broken slag, gravel or shell, with or without sand, Portland cement, fine inert material or combinations thereof, and a bituminous cement incorporated together by a mixing method." For an account of the derivation of the terms, bituminous macadam and bituminous concrete, see Sect. 15, Art. 1.

Classification. Bituminous concrete pavements may generally be grouped in three classes. The Spec. Com. Mat. Road Cons., Am. Soc. C. E. (17e), has defined the essential characteristics of the three classes as follows:

"CLASS A. A bituminous concrete pavement having a mineral aggregate composed of one product of a crushing or screening plant.

"CLASS B. A bituminous concrete pavement having a mineral aggregate composed of a certain number of parts by weight or volume of one product of a crushing or screening plant, and a certain number of parts by weight or volume of sand, broken stone screenings or similar material, with or without a filler.

"CLASS C. A bituminous concrete pavement having a predetermined mechanically graded aggregate composed of broken stone, broken slag, gravel or shell, with or without sand, Portland cement, fine inert material or combinations thereof."

Patent Litigation. In connection with the design or selection of a suitable type of bituminous concrete pavement, it is at present (1918) necessary to consider the possibility of an infringement suit being brought by one of the patentees of proprietary pavements. Highway engineers and contractors are primarily interested in the types of bituminous concrete pavements which may be constructed without danger of litigation rather than a voluminous discussion of the probabilities of successfully defending infringement suits.

CLASS A. There is ample evidence at hand that bituminous concrete pavements of Class A may be constructed without danger of litigation proceedings.

CLASS B. The history of litigation cases indicates that the construction of unpatented bituminous concrete pavements of Class B on a large scale will, in all probability, lead to an infringement suit.

CLASS C. With the exception of the class of bituminous concrete pavements having mineral aggregates similar to that covered by the Topeka decree, the extensive use of unpatented bituminous concrete pavements of Class C will usually lead to litigation proceedings.

PRIOR ART. For examples of early literature pertaining to mineral aggregates of the several classes of bituminous concrete pavements, see Art. 2.

PATENTED PAVEMENTS. For descriptions of the mineral aggregates of patented bituminous concrete pavements, see Arts. 6 and 7; for methods of manufacture and construction, see Arts. 14 and 16; and for specifications, see Arts. 15 and 17.

LIABILITY FOR INFRINGEMENT OF PATENTS. If a state, county or municipal department uses a specification for a non-proprietary bituminous concrete pavement of Class B or C, it generally should assume responsibility in case a suit for infringement is brought by a patentee. The practice of requiring the contractor to indemnify the party of the first part should not be followed, except in cases when specifications are used which have been advocated or drawn up by a producing company or a contractor. In the cases of the exceptions noted, the use of the following clause, or one similar thereto, in specifications is justifiable.

"The contractor shall indemnify and save harmless the city against all claims for any infringement of patents or royalty due on same on account of any methods or combinations of materials used on the herein specified work, or for use of any tools, machinery, appliances, devices, or materials used in the construction and completion of the work, and hereby agrees that the Director of Public Service may retain out of the moneys which may be due or become due said contractor under this contract a sum of money sufficient to cover all claims for damages or royalty as above mentioned, and to retain the same until the said claims are paid or satisfactorily adjusted."

N. Y. State Highway Comm. Method of Contracting for Patented Pavements as contained in its specifications for Bitulithic pavement.

"Warren Brothers, owners of the patents used in the construction of Bitulithic Pavement, have filed with the State Commission of Highways a properly executed binding agreement to furnish any contractor desiring to bid for the work all the necessary surface material mixed and ready for use, and bituminous flush coating cement necessary for coating the wearing surface, delivered on wagons of the contractor at the mixing plant, which will be located within 3 miles of the point of use, at a stipulated price per square yard for each contract. Such price for Bitulithic pavement mixture and flush coating composition will include a license to use all the patents required in the construction of the pavement as herein specified. The filing of a bid under these specifications will be construed as an acceptance of the terms of the license agreement filed by the Warren Brothers Co., at the price in said agreement, which is on file with the Secretary of the Commission."

Indemnity Bond for Patented Pavements by Warren (71e). "It is a common and good precautionary custom of municipalities in cases where advance arrangements have not been made for use of the patent to stipulate in the contract and contractor's bond that the contractor and surety shall indemnify the municipality against loss by reason of the infringement of patents involved in the construction. Such bonds should be in a sum sufficient to cover the probable royalty, the amount of which actually depends on the size of contract and in addition thereto at least $50 000, regardlessof the size of the contract, in order to safely cover the cost of defending litigation and the taxable costs in case the final decision is in favor of the patentee if litigation is brought by the patentee against the municipality as an infringing user."

2. Historical Development

The first bituminous concrete pavement was probably constructed about 1840 in Nottingham, England, while in the United States the first construction of this type of pavement was at Knoxville, Tenn., in 1866. From 1870 to 1875 there were about 70 000 sq yd of bituminous concrete pavements laid in Washington, D. C., see (23a). From 1888 to 1893 many yards of coal-tar distillate pavements were laid in Washington because Congress had prohibited the use of sheet-asphalt pavements in the District of Columbia. From 1880 to 1891 several sections of bituminous concrete pavements, using coal tar as the bituminous cement, were laid in Ontario, Can., see (47). Another early bituminous concrete pavement was built in Concord, N. H., and is still in use to-day. During the closing period of the nineteenth century attention was directed in England to the details of construction of bituminous concrete pavements for use on highways outside of built-up districts. In the United States at the opening of the twentieth century, Fred J. Warren urged the use of bituminous concrete as a pavement for streets in competition with sheet-asphalt, wood block, and brick pavements. Based on experimental work begun in 1906, Rhode Island in 1909 was the first state to adopt the bituminous concrete pavement as a standard type of construction for use on state highways. Since 1910 there has been a rapidly growing appreciation of the inherent value of the many different types of bituminous concrete pavements for use on roads and streets. Instances of development in this field of construction will be cited later, in connection with each class of bituminous concrete pavement.

Class A. Pavements of this type have been constructed of one or more courses of bituminous coated metal with and without seal coats of bituminous materials. During the period from 1869 to 1875 many patents were granted by the United States Government covering bituminous concrete of this type.

Patent No. 114 172, granted to F. E. Mathews in 1871, contains the following description of a two-layer bituminous concrete pavement:

" When laid on an ordinary foundation the concrete should be laid in 2 layers or coats and should be from 6 to 8 in thick when finished.

" For the first layer the stone used in making the concrete may be such as would pass thru a screen having a 3-in mesh; about 6 measures of the stone should be mixed with 1 measure of the asphalt mixture and this layer should be about 4 in thick.

" For the second layer or coat the stone should pass thru a screen having a 1½-in mesh, and be mixed with the asphalt mixture in the proportion of about 4 parts of the former to 1 part of the latter, and the second layer should be from 2 to 3 in thick.

" Fine sand or any suitable fine hard substance may be sprinkled over the last coat just before or after rolling, to give the pavement a smooth compact surface."

Many descriptions of old pavements of this type may be found in technical literature. As an illustration may be cited the following specifications used in England in the latter part of the nineteenth century: " The hot stone, when ready for mixing, is screened into material of 3 sizes, 1 to 2 in for the body, ½ to 1 in for the intermediate coat, and ¼ to ½ in for the top dressing. The coarsest material is used in a layer 3 to 4 in thick, the intermediate size forms a coat of about ¾ in, and the top dressing is used in the thinnest layer possible, with a view to filling all interstices. Afterward a dressing of ¼-in and smaller granite screenings is scattered broadcast, and the traffic at once allowed on the road to work this top dressing into the tarred material. Each of the layers is rolled separately with a 10-ton roller."

Class B. This type has been described many times in early technical literature. For example, the following description was published prior to 1885: " The manner of preparing, treating, and laying the asphalt mass is as follows: He took asphalt, 125 parts; petroleum-oil, 25 parts. These substances were melted and thoroly incorporated together, and to this mixture he added, in a heated state, sand or powdered stone, 750 parts, and gravel or broken stone, also heated, 1100 parts. The whole was then thoroly mixed."

U. S. O. P. R. Report on Tar Concrete Pavement Laid in 1875 on Highland Terrace, Washington, D. C.; date of report, Nov. 16, 1909. "This sample was taken from a section of about 2 sq ft cut from the old pavement on Highland Terrace, which was laid in 1875. The section was cut under the supervision of Hubbard and Reeve from midway between the center and gutter on the south side of the street near the middle of the square and a little to the right of the German Embassy when facing it. The general appearance shows it to consist of a dense aggregate of crushed rock and fine sand, thoroly impregnated and bound together with a bituminous cement. The surface consisted of a cushion layer of somewhat finer material than the body of the pavement, approximately ¼-in thick, but the presence of coarse stones was noticeable thruout the surface. This layer was so well incorporated with the body of the pavement that it could not be separated, and the determinations were made upon about 2800 g of recovered mineral matter. Sand was not noticeable in any of the portions above 80-mesh, but was present to a considerable extent in the fine portions.

Bitumen in pavement		6.2%
Mineral aggregate		
Stone retained on 8-mesh sieve		82.8%
Stone retained on 1-in screen	1.6%	
Stone retained on ¾-in screen	6.1%	
Stone retained on ½-in screen	35.7%	
Stone retained on ¼-in screen	41.6%	
Stone passing ¼-in screen	15.0%	
	100.0%	

Stone and sand passing 8-mesh sieve		17.2%
Retained on 10-mesh sieve	16.0%	
Retained on 20-mesh sieve	19.5%	
Retained on 30-mesh sieve	12.0%	
Retained on 40-mesh sieve	16.5%	
Retained on 50-mesh sieve	5.0%	
Retained on 80-mesh sieve	10.5%	
Retained on 100-mesh sieve	3.5%	
Retained on 200-mesh sieve	6.0%	
Passing 200-mesh sieve	11.0%	
	100.0%	
Voids in mineral aggregate		18.5%
Retained on ¼-in screen	70.3%	
Retained on 100-mesh sieve	26.7%	
Retained on 200-mesh sieve	1.0%	
Passing 200-mesh sieve	2.0%	
	100.0%	

Specifications for Washington, D. C. Coal Tar Distillate Pavement, as laid in 1887 (27d).

"The base will be composed of clean, broken stone that will pass thru a 3-in ring, well rammed and rolled with a steam roller to a depth of 4 in, and thoroly coated with hot paving cement composed of No. 4 coal tar distillate in the proportion of about 1 gal to 1 sq yd of pavement.

"The second or binder course will be composed of clean, broken stone, thoroly screened, not exceeding 1¼ in in the largest dimension, and No. 4 coal tar distillate. The stone will be heated by passing thru revolving heaters, and thoroly mixed by machinery with the distillate in the proportion of 1 gal of distillate to 1 cu ft of stone. The binder will be hauled to the work, spread upon the base course at least 2 in thick, and immediately rammed and rolled with hand and heavy steam rollers while in a hot and plastic condition.

"The wearing surface will be 1½ in thick when compacted, made of paving cement, composed of 25% of asphalt and 75% of coal tar distillate, mixed with other materials, as follows: Clean, sharp sand will be mixed with pulverized stone of such dimensions as to pass thru a ¼-in screen, in the proportion of 2 to 1. To 21 cu ft of the above-named mixture will be added 1 peck of dry hydraulic cement, 1 quart of flour of sulphur, and 2 quarts of air-slaked lime. To this mixture will be added 320 lb of paving cement to compose the wearing surface.

"The material will be heated to about 121° C (250° F); the paving cement in kettles, the sand, stone, etc, in revolving heaters. They will be thoroly mixed by approved machinery, and the mixture carried upon the work, where it will be spread upon the binder course 2 in thick with hot iron rakes and other suitable appliances and immediately compacted with tamping irons, hand and steam rollers, while in a hot and plastic state. The surface will be finished with a dusting of dry hydraulic cement rolled in. The pavement so constructed must be a solid mass 6 in thick, and will be thoroly rolled and cross-rolled until it has become hard and solid."

Pavements of Class B have been used in several municipalities since 1900. For example, in Washington, D. C., bituminous concrete pavements have been constructed in accordance with the following specifications covering the mineral aggregate: "The paving material shall be composed of crushed trap rock screenings, concrete sand, and mineral dust in the following proportions: Trap rock screenings, 2 parts; concrete sand, 1 part, and mineral dust, at least 5% of the above aggregate; mixed with asphaltic cement." The trap rock screenings referred to above varied in size from 1 in to screenings and were devoid of dust. See Art. 6.

Class C. Specifications for pavements of this type call for predetermined mechanically graded aggregates. From a historical standpoint reference

is made to the description of the Excelsior Pavement, as it includes the characteristic features of this class, namely, that "several sizes are mixed to form a close mass without cavities." This description is made up of pertinent abstracts from a book entitled "The Excelsior Pavement," the advertisement of which is dated 1871.

"The Excelsior Pavement consists of a broken stone, or McAdam base, covered with a concrete surface, which, being close, smooth, and coherent, presents but little resistance to travel, and permits no movement among the stones that compose it; therefore, scarcely any dust or mud is formed; its superiority over others is manifest.

"The resisting material may be sand for the surface, gravel or broken stone mixed with sand for the middle, and larger stone for the bottom, or bed; broken stone alone is preferred, sizes being chosen which best form a compact structure, smooth on top, and strong thruout. Small fragments are not generally required. Several sizes are mixed to form a close mass without cavities, the coarser stone being put beneath. This material should be carefully selected for its strength and resistance, and contain no dirt or other foreign matter.

"The sand, gravel, or broken stone of different degrees of coarseness, as laid at or below the surface, should be sharp, clean and hard; the cement should be uniform, fluid and adherent during mixture; and the compound should condense and harden rapidly under manipulation, being composed of the greatest amount of rock, and the least of cement, which will form a mass most resembling stone itself."

In 1907 the author discovered a printed specification in the Library of the Am. Soc. C. E. entitled "Specifications for the Excelsior Pavement." The following excerpt covers the description of the mineral aggregate:

"Broken stones are preferred for the whole pavement, and shall alone be used for the covering. The greatest dimension of stones for the base, except as hereinafter noted, shall be between 3 in and ¼ in, and for the covering between 2 in and 1/20 of an in; the sizes shall be mixed in proportion, varying with the size to form a close mass, which, when dry and compact, can absorb not more than 20% of water."

Bitulithic Bituminous Concrete Pavement. Since the beginning of the twentieth century a large amount of a proprietary pavement known as "Bitulithic" has been laid in the United States. As described by Fred J. Warren, the wearing surface, which usually has a thickness of about 2 in after compression, is constructed as follows: "The mineral or stone part is dried and heated in a modern drier and is then separated by screening with a rotary screen into its sizes, varying from fine dust, which is less than 1/200 of an in in diameter, to the largest size used. The several sizes of stone are then mixed in predetermined proportions, so as to reduce the voids to about 10%, in a modern twin plug steam power mixer, and the hot bituminous cement is added in the mixer in sufficient quantity to not only coat every particle and fill all of the remaining voids, but with enough surplus to furnish to the mixture after compression a rubbery and slightly flexible condition." See Art. 7.

Topeka Bituminous Concrete Pavement. Since 1911 many thousands of yards of pavement of Class C have been laid under the so-called Topeka specifications. A decree was signed in 1910 by certain city officials and representatives of the Warren Brothers Company covering the use of the Topeka mineral aggregate. The following quotation is from the decree to which reference has been made: "It appearing to the court that

of the mineral matter used in the pavements actually constructed in the cities of Topeka and Emporia, Kan., no particles of stone were used that would not pass a screen with openings ½ in in diameter, and that less than 10% of the stone or coarse sand used would be retained upon a screen with openings ¼ in in diameter, and the remaining mineral matter used being finer than ¼ in; and it further appearing that pavements constructed by the use of mineral particles as above described do not infringe the claims of complainant's patent No. 727 505, sued upon in this case; . . . And it further appearing that the pavements as actually constructed in the cities of Topeka and Emporia, Kan., do not infringe the claims of complainant's patent No. 727 505, sued upon in this case, and that any pavements hereafter constructed in substantial compliance with the following formula, to wit:

"Bitumen, from 7% to 11%
Mineral aggregate, passing 200-mesh screen, from 5% to 11%
Mineral aggregate, passing 40-mesh screen, from 18% to 30%
Mineral aggregate, passing 10-mesh screen, from 25% to 55%
Mineral aggregate, passing 4-mesh screen, from 8% to 22%
Mineral aggregate, passing 2-mesh screen, less than 10%

sieves to be used in the order named, would not infringe the claims of said patent." See Art. 7.

Seal Coats on Bituminous Concrete Pavements. The value of the use of seal coats of bituminous cements was appreciated by some of the pioneers in this field of highway improvement. In 1876, Abbot (1) presented the following pertinent discussion on this detail of construction:

"It is the practice of most of the concrete pavement men to finish the surface with a top dressing of dry sand, rolled into the surface; or of hydraulic cement, swept in with a broom. I became early satisfied that some better plan of finishing was needed. The most compact concretes are more or less porous on the surface; and tho these pores are filled with the sand or cement used for top dressing, neither of these materials being waterproof, in wet weather the water penetrates the pavement, street dirt mingles with the water, and a disintegrating process begins, which soon results in breaks and unevenness of surface. In winter, particularly, the moisture, having penetrated the pavement, freezes and thaws, and decay is hastened. It is just as essential that a concrete pavement should be waterproof as that a roof should not leak. My experiments in this direction resulted in what is known as the Abbot Grit Surface, which was patented June 17, 1873. This improvement consists in spreading a hot liquid composition over the surface of the pavement after it is rolled, into which is placed clean, dry grit or sand. This sand is immediately rolled into the surface while the composition is warm, and a tough coating is thereby formed, which not only prevents the pavement from being slippery, but effectually closes every pore in the surface, and makes it impossible for moisture to penetrate."

3. Characteristics

Advantages. All of the advantages resulting from the construction of bituminous surfaces on macadam and gravel roads (see Sect. 14) and of bituminous macadam pavements (see Sect. 15), except low first cost and rapidity of construction, may be cited verbatim with reference to bituminous concrete pavements. Bituminous concrete pavements are usually more stable and durable than other bituminous pavements constructed with

broken stone, gravel, or broken slag. The methods employed in the construction of bituminous concrete pavements permit the most suitable kinds and grades of bituminous cements to be used. The proper use of mixing methods insures homogeneous wearing courses having all particles of the aggregates uniformly coated with bituminous cement. As the aggregate is usually heated at a mixing plant, delays of construction, due to wet weather, are not as prolonged as in the case of bituminous macadam pavements. By the use of modern mixing plants, it is practicable to lay certain types of bituminous concrete pavements of Class A as economically as it is possible ordinarily to build bituminous macadam pavements.

Disadvantages. Slipperiness with seal coats of some bituminous materials may occur and thus prove a disadvantage. Skilled labor is required, and, for some types, expensive plant equipment is essential.

4. Drainage, Subgrades, Foundations and Edgings

Drainage. As bituminous concrete pavements are impervious, the utmost care must be taken to secure, by thoro underdrainage, dry, natural foundations. If the road-bed is not properly drained, water may be held in contact with the undersurface of the wearing course and cause disintegration; in other cases displacement of the wearing course is liable to take place due to freezing and thawing of the road-bed, settlement of embankments, the force of water from springs, and the general weakening of the natural foundation. The use of cement-concrete foundation or broken stone foundations does not prevent underground water from reaching the bituminous wearing course as both types are pervious to water. For a detailed discussion of underdrainage, see Sect. 8, Arts. 6 and 7.

Subgrades. For methods of constructing subgrades, see Sect. 8, Art. 3.

Foundations. For all classes of bituminous concrete pavements, foundations of gravel, broken stone or slag, old macadam, bituminous macadam and concrete, old brick and stone-block pavements, and cement-concrete have been used. The foundation should be strong enough to carry the traffic to which the pavement is to be subjected. Many failures have occurred due to laying bituminous concrete pavements on weak foundations. Satisfactory results have been obtained under medium traffic with thoroly filled and compacted broken stone, and bituminous concrete foundations. Cement-concrete foundations have been used successfully under the heaviest traffic for which the several classes of bituminous concrete are suitable, especially in cases where the road-beds have been well drained. For a discussion of the relative advantages and the methods of construction of the different kinds of foundations see Sect. 8, Arts. 10 to 20 inc., and Sect. 17, Art. 3.

Penn. State Highway Dept. Practice Relative to Foundations by Uhler (66). "Bituminous concrete and sheet-asphalt pavements should be laid on a concrete base, instead of on the old existing macadam foundation, which, heretofore, has been the generally accepted practice for country roads. In view of the increased amount and change in character of traffic, even tho slightly more expensive, it is advisable to provide for either a 4 or 5-in concrete base on top of the broken stone or telford base, due to the tendency of macadam to shift or to consolidate further under traffic and possible subgrade trouble, all of which tend to bring about a wavy or uneven condition of the surface. In resurfacing old water-bound macadam roads, where the base consists of either telford or macadam, the broken stone surface should be removed to a depth sufficient to conform to the required cross-section and grade. Where the telford surface is exposed, the irregularities are broken off with a napping hammer and the depressions filled in, and upon this prepared surface is placed a 4-in concrete base,

mixed in the proportion of 1:3:6, laid so as to secure a very rough but regular surface to form a bond between the concrete base and the bituminous top. In conjunction with the concrete base a concrete header curb should be constructed extending 6 in beyond the fixed edges of the bituminous pavement and to the finished grade. After the concrete base has developed a hard set, and from 1 to 2 days prior to the placing of the bituminous wearing surface, the base should be cleaned thorgly of loose and foreign material, by sweeping, and then covered with an asphaltic cut-back mixture consisting of equal parts, by volume, of asphaltic cement, 55 to 65 penetration, and commercial naphtha, 52 to 55 gravity, the mixture being applied by a pressure distributor at the rate of 1/8 gal per sq yd. The object of this paint coat is to secure a better bond between the concrete base and the bituminous top."

Specifications for Subgrade, Sub-Drainage and Foundations Adopted in 1916 by the Am. Soc. Mun. Imp., as a part of the specifications for Topeka and Bitulithic pavements.

"**Subgrade.** The contractor will be required to do all of the grading necessary to bring the surface to the proper subgrade as determined by the lines and grades given by the engineer. If the material at subgrade is of an unstable character and unfit for foundation, the contractor shall make such additional excavation as may be determined by the engineer and refill with approved material. After all necessary grading has been done to bring this surface to subgrade, the street shall be thoroly rolled with an approved road roller weighing not less than 10 tons. If settlement occurs the depressions shall be filled and then re-rolled until the surface is solid, uniform and parallel with the grade and cross-section of the finished pavement. All filling shall be free from animal or vegetable matter and of a character approved by the engineer. In case of spongy or yielding subgrade some other means besides ordinary rolling and sprinkling must be employed to obtain satisfactory compaction of the subgrade. In case of loose, sandy soils, a small amount of cinders, gravel or fine crushed stone spread over the surface will often put it in a condition to be compacted under the roller. In the case of clay soils that puddle up and wave or creep under continued rolling, it is best to roll as dry as possible and to be sparing in the use of water when rolling the first layer of macadam. Cinders, gravel or stone screenings will often help in rolling such subgrades.

"**Sub-Drainage.** When the soil is of such a character that it retains an excessive amount of moisture, such as clay, subject to swelling or heaving under the action of frost, or sands similar to quicksand that do not afford a ready natural drainage, subdrains should be provided. These may be of two general kinds: (1) Tile drains of porous material or of vitrified tile laid with open joints; (2) trenches filled with broken stone, gravel, cinders or other similar material. In some cases it may be sufficient to construct a sub-drain on each side of the roadway at or near the lines of the gutters, but when the soil is of a very wet nature it may be advisable to lay additional lines of drains which may be in or near the middle of the roadway. This system of drains may be varied by diagonal lines of drains running from near the crown of the roadway to the gutters. In all cases the drains should have connections with the existing sewers, catch-basins or inlets.

"**New Macadam Foundation.** If the pavement is to be laid on a new macadam foundation or base, the latter shall be built as follows: The total thickness of the macadam base will vary according to character of soil, drainage, kind of stone available, etc. In general, the macadam base should be constructed of broken stone which is sound, hard and durable under traffic. The broken stone should be separated into different sizes by screening, the smaller sizes with the dust being used to fill and bond together the larger sizes. The thickness of the base should be regulated by experience in constructing ordinary water-bound macadam roads in similar situations, the total thickness of pavement, including wearing surface, being made the same or a little less than well constructed macadam.

"After the subgrade has been carefully prepared, spread a layer of clean stone passing a 3 to 3½-in revolving screen and held on a 2-in screen to a depth sufficient when thoroly rolled to form about ⅔ of the total thickness of the base. The thickness of this layer should be regulated by laying on the subgrade at proper intervals, cubical blocks of wood of the proper dimensions to give the desired thickness. Over this layer of stone, spread, with shovels, stone screenings in sufficient quantity to fill the

voids between the larger stone. The screenings should be spread gradually and thoroly rolled with a road roller weighing at least 10 tons during the process of spreading the screenings. As the screenings are worked into the coarse stone under the roller, more should be added here and there where voids appear. At first the rolling should be done dry until the stone appears to be well filled, then the surface should be well sprinkled and again rolled, the rolling and sprinkling continued until the layer of stone is thoroly compacted and no more screenings can be forced in. Just enough screenings shall be used to fill and bond the stone, leaving no surplus screenings on th top.

"The above method may be varied by using the crusher run of stone without addition of any other filler where the small sizes are not in excess. Also a filler other than stone screenings, such as bank gravel or sand, may be used in some cases where experience with materials available shows better results can be obtained. Under some conditions the character of soil and stone available may be such as not to require the use of any filler with the stone of the first course. The specifications given, however, represent the best average practice where stone with bonding value, such as limestone or trap rock, can be obtained.

"When the first layer of macadam is completed as specified, spread a second layer of clean stone passing a 2 or 2½-in screen and held on a 1-in screen to a depth sufficient when thoroly rolled to form the remaining ⅓ of the total thickness of the base. Over this layer of stone spread evenly with shovels stone screenings and roll with the application of water by sprinkling. The sprinkling and rolling shall be continued until the stone is well bonded and until no more compression can be observed under the roller. Just enough filler should be used to accomplish this purpose and not enough to form a layer or film over the surface of the stone. It is better not to fill the stone quite flush, leaving the coarse particles of stone slightly projecting, so as to have a coarse, grainy base upon which to put the wearing surface.

"As an alternate method of construction, the macadam may be well filled with screenings, watered and rolled until flushed up smooth. Over the surface of the macadam base thus constructed shall be spread a third layer of clean stone of a size to pass a 2-in ring and be retained on a 1-in ring. This layer of stone should average 1 in after rolling or practically only one stone deep and is for the purpose of forming a binder or key between the base and wearing surface and thus preventing lateral displacement of the surface. After being spread evenly it shall be lightly rolled only enough to partially imbed the stone and set them firmly in place without crushing or forcing sufficient fine material up from below to fill the surface voids entirely. The final rolling should be done while the macadam base is still moist and comparatively soft.

"The thickness of the pavement, including base and wearing surface, should vary according to local conditions and should be fixed by the engineer in charge when all the varying conditions of soil, drainage, traffic and materials of construction are understood. In general, a thickness of macadam base of 8 in with a wearing surface of 2 in will be enough for any except the most adverse conditions, and a base of 4 to 5 in with a wearing surface of from 1½ to 2 in will meet the most favorable conditions of firm, unyielding soils and light traffic.

"Old Macadam Foundation. If the pavement is to be laid on an old macadam foundation, the surface shall be thoroly swept and cleaned of all fine material that may be caked upon the surface of the stone or lying loose as dust, thereby exposing the clean, coarse stone for the reception of the bituminous concrete. If the old macadam does not present the desired coarse, grainy surface, or is not at proper and satisfactory grade after cleaning, it shall be spiked up and redressed to the desired crown and grade, the coarse stone being brought to the top by harrowing or otherwise, or new stone added where needed. It shall then be watered and rolled until thoroly compacted. If the result is not the required coarse, grainy surface, a layer of clean stone shall be spread and lightly rolled as described above in the paragraph relating to new macadam foundation.

"Cement-Concrete Foundation. When a Portland cement-concrete foundation is used, it should be laid according to the standard specifications adopted for concrete foundation. The surface, however, should be roughened to form a key for the wearing surface. This may be done by using coarse stone of fairly uniform size and laying

the concrete fairly wet, or by brooming, washing with a hose before hard set, tamping with grooved rammers, or by spreading a light layer of coarse, clean stone over the fresh concrete and lightly tamping."

Protection of Edges of Bituminous Concrete Pavements. The edges of bituminous concrete roadways on streets are protected, as they are usually built between sidewalk curbs or between paved gutters of brick, stone block, or cement-concrete. In the case of bituminous concrete pavements outside of urban districts, however, the edges generally are not supported by gutters or sidewalk curbs. Many roadways are built with earth shoulders adjoining the bituminous concrete. Under such conditions, especially when the width of roadway is not adequate to accommodate the traffic, the inevitable result is the breaking off of the edges of the bituminous concrete. Instances have occurred on 16-ft roadways, subjected to heavy commercial traffic, where, during 1 year, the edges have been broken off for a width of 4 to 10 in.

Abnormal wear of edges may be prevented by several methods: (1) Increasing the width of the roadway of bituminous concrete so that the probable traffic will not be forced near the edges. (2) Construction of thoroly compacted and puddled shoulders of gravel or broken stone with or without thin bituminous surfaces. (3) Use of edgings of wood, steel shapes, stone block, cobblestones, or cement-concrete. (4) Construction of the English or French raised verge or shoulder which has a depth of 3 to 5 in.

In the United States, cement-concrete edgings or curbs are most generally used. They should be built of 1:1½:3 or 1:2:4 cement-concrete, and have a width of not less than 6 in. However, their use should not be considered an argument for the construction of roadways having widths inadequate to carry the traffic to which they probably will be subjected. If the roadways are not wide enough to accommodate the traffic, usually bad ruts will be worn in the bituminous concrete adjacent to the cement-concrete edgings, the formation of the ruts being followed by the breaking off of both the cement-concrete edgings and the bituminous concrete.

The method to be adopted in any particular case will depend upon the amount and character of the probable traffic, the available width for the roadway and other parts of the highway, the comparative economical value of the different methods of protecting the edges based on local conditions, and the amount of money immediately available for the improvement.

Conclusions. Spec. Com. Mat. Road Cons., Am. Soc. C. E. (17e). "Where bituminous pavements are laid, the edges need protection, and a sudden transition from the pavement to any soft shoulder material should be avoided by means of extra width, or of cement-concrete or other edges, or such reinforcement of the shoulder material as may be necessary."

Economy of Using Cement-Concrete Curbs (50b). "The good reputation of asphalt wearing surfaces is based largely upon the performance of such surfaces on city streets, where curbs are almost invariably provided. In proportion to the traffic carried, such side support is just as necessary on roads as for pavements. A very good example of the truth of this statement was noted recently (1917) during the inspection of a Long Island Topeka specification road, now 5 years old, and in good condition except along the edges, where the asphalt top was almost continuously broken down along the shoulder of the road. The maintenance of something more than a mile of this road for the 5-year period would have amounted to practically nothing but for the repairs necessary at the edges of the road, all of which would have been avoided if a concrete curb or header had been provided in the first instance."

U. S. O. P. R. 1916 Specifications for Cement-Concrete Edgings. "Concrete curbs shall be built on the base as shown on the plans. The concrete shall be composed of the following materials, by volume: 1 part of cement, 1½ parts of sand, 3 parts of gravel or crushed stone, and water. The materials shall be thoroly mixed in a machine

mixer of the batch type or by hand. If the mixing is done by hand, it shall be done upon a water-tight platform with raised edges, in such manner as to insure thoro mixing of the materials and to meet the approval of the engineer. The concrete for the curb shall be placed upon the base before the concrete of either the curb or the base has taken its initial set, and care shall be taken, such as roughening the concrete of the base and tamping the concrete of the curb, to insure that the curb will be firmly bonded to the base. The concrete shall be well tamped and spaded along the forms, so that when they are removed there will be no open and porous places on the sides of the curb. The top surface of the curb shall be floated or troweled to a smooth finish. The forms for the curb shall be smooth, clean, free from warp, and of sufficient strength to resist springing out of shape. They shall be well staked and braced, and the top edges shall be at the same height and set true to line. To protect the curb from drying out too rapidly it shall, within 12 hr after it is placed, be covered with gunny cloth, which shall be kept wet for 5 days."

MATERIALS

5. Mineral Aggregates for Class A Pavements

Class A Bituminous concrete aggregates consist of one product of a crushing or screening plant. The non-bituminous materials used as aggregates for Class A bituminous concrete pavements are broken stone, broken slag, gravel, and oyster shells. Broken stone and broken slag are the principal materials used, due primarily to the desirable stability being more readily obtained than with gravel, while the use of oyster shells has resulted from consideration of low first cost in some sea-coast districts.

Broken Stone. Trap rock, limestone, granite, and syenite have been used extensively, and, to a limited extent, sandstone, gneiss, and field stone have been employed. Altho trap rock generally makes the best aggregate for pavements subjected to heavy commercial traffic, and gneiss and field stone make unsatisfactory aggregates, the latter due to its non-uniform qualities, it is poor practice to specify acceptable rock merely by geological names (see Sect. 11, Art. 5). The rock should meet definite physical requirements, which will depend upon the traffic to which the pavement will be subjected, local economic factors, and, in some cases, details of the method of construction. It is desirable that the broken stone be hard, to resist wear caused primarily by the grinding action of iron-tired vehicles, and tough, to resist impact forces such as blows of horses' hoofs and the hammering action of heavy iron-tired wheels as they pass over obstructions on the surface of the roadway. Altho the Dorry test is used as a direct measure of hardness, the Deval test gives the only reliable indication of the resistance to abrasion of broken stone. The limiting values to be given to resistance to abrasion and toughness requires consideration of all local conditions. If, for example, the roadway is to be subjected primarily to rubber-tired motor vehicle traffic, a rock having a toughness of not less than 6 and an abrasion loss of not more than 6%, would give good results. If used on a roadway carrying a daily commercial traffic of 300 iron-tired horse-drawn and motor trucks, a rock having a toughness of not less than 13 and a loss of abrasion of not over 3.5% should be used.

Shape, Character of Surface and Cleanliness. See Sect. 15, Art. 5.

Products or Sizes. Due to the variability in the sizes of particles of broken stone contained in products obtained under the common forms of specifications, it is usually necessary to adopt more rigid requirements covering the composition of the product rather than its method of manufacture. For a discussion of variation in products of broken stone, see Sect. 11, Art. 6. For specifications and formulas covering the composi-

tion of broken stone products, see Art. 8, AM. SOC. MUN. IMP. CLASS A SPECIFICATIONS, and Sect. 11, Art. 7, AM. SOC. C. E. AND AM. SOC. TEST. MAT. FORM OF SPECIFICATION. If broken stone is obtained from stationary commercial plants, the methods to which reference is made always should be used. In case of portable plants, altho the specification form recommended is the most satisfactory for general use, local conditions may be such that the following type of specification will prove more adaptable, especially in cases where contractors or local quarrymen are not accustomed to furnishing broken stone to meet requirements covering the several sizes of broken stone in a product.

"For the wearing course 1½-in stone shall be used, and stone chips shall be used for the seal coat. The screening plant or plants for supplying broken stone shall be equipped with revolving screens, 9 to 12 ft long and from 30 to 36 in in diameter, having perforations as follows: First section, ½-in holes; second section, 1½-in holes; third section, 3-in holes. The sections of screen shall be of acceptable lengths. A dust jacket having ¼-in circular perforations or composed of a 4-mesh sieve shall surround the first section; it shall be 6 to 9 in shorter than the ½-in screen and about 6 in greater in diameter. Broken stone dust passing the ½-in screen and retained on the dust jacket is designated in these specifications as stone chips. Broken stone passing over the ½-in screen and thru the 1½-in screen is designated as 1½-in stone."

In using specifications of the above type, a clause should be inserted which would require that the crushing and screening plant be operated in accordance with the direction of the engineer in so far as such operation effects the composition of the several products of broken stone. The specifications quoted were used with successful results by the Board of Water Supply of the City of New York in connection with the construction of 32 miles of Class A bituminous concrete pavements. Seven crushing and screening plants were efficiently operated under the direction of the Board's engineers in order to obtain the products desired for the foundation course, the wearing course of bituminous concrete and the stone chips for the seal coat.

ANALYSES OF AGGREGATES FOR ONE-LAYER PAVEMENT. The following analyses of aggregates from three different contracts are given as illustrations of satisfactory products for use in the construction of one-layer pavements of Class A when broken stone or broken slag is used for the aggregate. By reference to Art. 8, it will be seen that all of the products meet the requirements of the Am. Soc. Mun. Imp. specifications.

	A	B	C
Passing ⅛-in screen	1.2%	2.7%	1.0%
Passing ¼-in screen	4.2%	5.6%	2.5%
Passing ½-in screen	34.7%	45.0%	30.8%
Passing ¾-in screen	40.6%	35.1%	34.2%
Passing 1-in screen	17.3%	10.1%	23.4%
Passing 1¼-in screen	2.0%	1.5%	8.1%
	100.0%	100.0%	100.0%

AGGREGATES FOR TWO OR THREE-LAYER PAVEMENTS. Many combinations of products have been successfully used in the construction of two and

three-layer bituminous concrete Class A pavements in England. For examples of English practice, see Art. 12. Altho pavements of this type have been constructed in the United States and Canada, its use since 1900 has been confined to a few localities. The AMIESITE pavement, see Art. 15, altho laid in layers, is not referred to here, as it comes under Class B pavements.

Broken Slag has not been extensively used in the United States. The excellent bituminous slag concrete pavements which have been constructed in England since 1900 indicate that from slag, possessing the essential physical and chemical properties, an aggregate, equal in quality to one of broken stone, can be manufactured. To make a satisfactory aggregate, slag must be clean, rough-surfaced, dense and tough, and possess no glossy surfaces. The Ohio State Highway Dept. requirements are as follows: "The broken slag shall be clean, sound, durable, and of uniform quality and shall contain not less than 32% of silica and not more than 25% of calcium oxide and not more than 1.5% of sulphur. Slag shall show in the abrasion test a loss of not more than 10%, a hardness of not less than 16, and a toughness of not less than 5. Slag aggregates shall weigh not less than 75 lb per cu ft." A slag, meeting the Ohio specifications, should only be used on light traffic roads. The slag used in England is so dense that it resembles trap rock, and has a high toughness and a low loss on abrasion.

SIZES OF SLAG. In England, slag is used for one, two, and three-layer bituminous concrete pavements of Class A. Typical English commercial products of slag are as follows:

2¼-in gauge, pieces varying from 2¼-in to 1½-in;
1½-in gauge, pieces varying from 1½-in to ½-in;
⅝-in gauge, pieces varying from ⅝-in to ⅛-in.

If used in three layers, the 2¼-in product would be used for the bottom layer, the 1½-in for the middle, and the ⅝-in for the top layer. For details of use, see Art. 12.

Gravel. Due to the variability in the composition of bank gravel, the probability that the particles of gravel will be coated with more or less clay, and the characteristic rounded surfaces of gravel, the use of gravel for Class A bituminous concrete has been very limited. If crushed, clean gravel is used, the results may be satisfactory, but it should not be expected that the resulting pavement will be as durable as one having an aggregate of well interlocked broken stone or broken slag. For specifications covering essential properties of gravel for bituminous concrete aggregates, see Art. 8.

Conclusions, Spec. Com. Mat. Road Cons., Am. Soc. C. E. (17e). "Broken stone, because of the satisfactory bond secured, should be used wherever possible, altho bituminous concretes constructed with gravel have proved satisfactory for light traffic where great care has been taken in the selection of the gravel and in the construction of the pavement.

"Broken stone should be clean, rough-surfaced, sharp-angled, of compact texture, and uniform grain. If the pavement is to be subjected to medium or heavy traffic, the broken stone used for the construction of the wearing course should show a loss or abrasion of not more than 3.5%, and its toughness should not be less than 13.

"Especial care is required in drafting the specifications covering the broken stone or gravel to be used. An excess of large or small sizes of stone or gravel should be avoided. Practice has demonstrated that a mineral aggregate which will comply with the following mechanical analysis, using laboratory screens having circular openings, will produce satisfactory results: All the material shall pass 1¼-in screen; not more than 10% nor less than 1% shall be retained on a 1-in screen; not more than 10% nor less than 3% shall pass a ¼-in screen."

Essential Physical Properties of Gravel, Slag and Broken Stone by Smith (60b). "GRAVEL should be clean grained, hard, and free from adhering clayey particles. It is lacking in stability owing to the roundness of its particles and is usually considerably improved by passing it thru a crusher. Gravel with a rough pitted surface is to be preferred and gravel containing a large percentage of flinty particles is to be avoided. It is unsuitable for the construction of pavements carrying heavy traffic and inferior in all respects to crushed stone.

"SLAG. Hard, dense, basic slag is to be preferred. Should be stable when exposed to weather and not show any tendency to slack or disintegrate. Only suitable for light traffic and should preferably be coated with a very fluid bitumen.

"BROKEN STONE. Should be freshly crushed, preferably in cubical shaped particles. Size and hardness required depends upon the traffic which the pavement is to carry. Dense hard limestone will carry medium and light traffic satisfactorily. When the traffic, tho light in volume, is composed of heavy iron-tired units, a dense hard trap is required. Trap is now commonly used for asphalt block manufacture, altho in the past a large number of asphalt blocks made from limestone gave excellent service under light traffic. Granite is not usually satisfactory as it is too coarse and uneven in texture and much of it is friable and it is liable to shatter in crushing."

Character of Surface of Gravel, Slag and Broken Stone by Smith (60b). "Broadly speaking, a rough, pitted and somewhat absorbent surface is the best. Smooth glossy surfaces do not readily retain a thick coating of bitumen and require a relatively high heat to insure properly coating them. At a high heat the bitumen becomes very liquid and readily runs off of them, which results in a coating of undesirable thinness. Even when the temperature at which they are coated is no higher than that employed with rough surfaces, their smoothness permits the bitumen to drain off more readily. This is particularly the case with flint particles; and sand containing them, when coated with bitumen and examined under a glass, invariably show the minimum thickness of coating on the flint particles sharply contrasting with the surrounding rougher surfaced quartz particles which have retained a coating of normal thickness. As compared with a non-absorbent surface, an absorbent one *per se* is to be desired. Unfortunately most particles which have absorbent surfaces are lacking in resistance to wear and therefore, notwithstanding their superiority from the standpoint of coating them with bitumen, are not suitable for heavy traffic, more especially of the iron-tired variety. Where the bituminous cement used is lacking in cementing value an absorbent surface is especially necessary.

"The outer surface of the particles must be firmly adherent to and form a permanent part of the particles themselves and must show no tendency to scale off when heated. Certain sands upon heating appear to form loosely adherent scales upon the surface of their particles which are not removed by attrition in the mixer but which under the stress of traffic and atmospheric changes in temperature become loose and detach themselves, carrying the coating of bitumen with them. Pavements laid with this type of sand have been known to disintegrate from this cause alone within a few weeks from the time they were laid. Gravel, freshly broken slag, and stone are ordinarily free from this defect. Slag which is glassy does not coat as well with bitumen as do the more basic slags."

Maximum Size Stone in Bituminous Concrete by Warren (71b). "Our practice on this point has always been to have the maximum sized stone in the aggregate 40 to 50% of the thickness of pavement surface except that on crushed stone or bituminous base a larger sized stone may be used, because a considerable portion of the larger particles of aggregate will crowd into the spaces between the coarse, generally 3-in, stone in the foundation and in reality make the total wearing surface 50% greater than the 2 in specified."

6. Mineral Aggregates for Class B Pavements

Class B bituminous concrete aggregates consist of a certain number of parts by weight or volume of one product of a crushing or screening plant, and a certain number of parts by weight or volume of sand, broken stone screenings, or similar materials, with or without a filler.

Broken Stone, Broken Slag and Gravel. For discussion of essential physical properties, see Art. 5,

Sand and Filler. For discussion of different kinds of sands and filler and the essential physical properties thereof, see Sect. 17, Arts. 4 and 5.

Filler for Aggregates by Mullen (49c). "The inorganic dust or filler is a factor of prime importance. The material most commonly used is limestone dust pulverized in a grinding mill to such fineness that at least 75% will pass a standard 200-mesh testing sieve. When the material is less fine, more must be added to secure a given result. Stone dust and Portland cement are the most widely used filler materials, the former being the most common because the lower in cost, but the latter being preferred by some on the ground that it is thought to make a superior mixture. When Portland cement is employed, the difference in specific gravity between that material and the remainder of the mineral aggregate should be taken into consideration, as the mixtures are usually figured by weight instead of by volume, tho the latter would seem a more logical method if it could be used with reasonable convenience. Other filler materials are pulverized clay, marl, shale, silica, etc. Many materials have been tried and found satisfactory, but a few have produced disastrous results. The 200-mesh sieve is not a sufficient test for an inorganic dust filler, except for routine work on a known material. The particles of dust that are of the most value are those that would pass a 500-mesh sieve, were one of such fineness of practical value for laboratory testing."

Composition of Aggregates. The conclusions of the Spec. Com. Mat. Road Cons., Am. Soc. C. E. (17e) are as follows: "Specifications for pavements of this class have generally stipulated that so many parts of broken stone or gravel and so many parts of sand or other fine material are to be mixed with a certain quantity of bituminous cement. By the use of this specification, and with unusual supervision, it is practicable to secure a fairly well-graded aggregate, but in most cases the mixture will be found to contain an excess of broken stone, with insufficient fine material to fill the voids therein, and in other cases it will contain an excess of sand in which the broken stone is held as isolated particles."

A typical specification covering the mineral aggregate of a Class B pavement is as follows: "The stone to be used shall be good, durable granite, trap rock, or limestone, and shall be the run of the crusher passing a 1½-in ring and shall not contain more than 5% of dust. Clean, coarse sand shall be used as a filler in the proportions found necessary and approved by the engineer in charge. The bituminous concrete shall have the following composition: Crushed stone, 53 to 62%; sand, 30 to 37%; asphalt cement, 8 to 10%." In this form of specification, a rough attempt is made to fill the voids in one product of a crushing and screening plant by a mortar of sand and asphalt cement. Altho a satisfactory mix may result, there is no assurance that a well-proportioned aggregate will be obtained. As explained in Sect. 11, Art. 6, the composition of broken stone products vary to a marked degree when furnished under the above type of specification. Further, the requirement that a definite percentage of coarse sand be used is no guarantee that the sand will be composed of the proper sizes to combine with the product of broken stone which the contractor or producer will furnish. To secure the best mix obtainable for Class B pavements, the broken stone product should be specified as recommended in Art. 5, and definite specifications should be used covering the sand and filler similar to those found in the specifications for Topeka aggregates, see Arts. 8 and 17.

Conclusions on Composition of Mortar by White (73b). "Following are the analyses of the mortar constituent, that is, 10-mesh material or less, of several samples of asphaltic concrete which have been under traffic for long enough periods of time to demonstrate their good or bad qualities. The first four proved to be very good, and the latter two indifferent in quality.

	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
Bitumen	18.8%	18.9%	16.1%	21.0%	18.9%	16.3%
Passing 200-mesh sieve	10.8%	11.6%	11.7%	10.9%	4.3%	3.5%
Passing 80-mesh sieve	10.6%	11.5%	7.0%	26.2%	5.9%	5.7%
Passing 40-mesh sieve	36.8%	35.3%	22.7%	19.3%	50.3%	54.1%
Passing 10-mesh sieve	23.0%	22.7%	42.5%	22.6%	20.6%	20.4%
	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

"As far as the coarse aggregate is concerned, that is, all material coarser than 10-mesh, there were considerable variations in the different samples, but the total quantity was approximately the same, and the variations seemed to have nothing to do with the success or failure of the sample. Samples 1 to 4 were successful, and they were rich in dust and reasonably well proportioned in other sizes up to 10-mesh. Samples 5 and 6 were practically failures, and they are seen to be lean in dust with an excess of 40-mesh material not well filled by the smaller sizes."

Washington, D. C., Aggregates, as described by Brooke (23b). "The proportions of coarse and fine aggregate for the bituminous concrete were fixed after a number of sieve tests of local sand and trap rock at about 2 parts by volume of stone to 1 of sand, to which is added about 5% of dust to supply the deficiency in fine material of the stone aggregate. The ingredients consist of crushed trap rock devoid of dust and varying in size from 1 in to screenings, sand, mineral dust and asphaltic cement. A hard-grained, moderately sharp sand is used. Upon sifting at least 25% must be caught on a 20-mesh sieve and 5% pass an 80-mesh. A deficiency in fine sand may be corrected with mineral dust, which consists of fine Portland cement or limestone dust, at least 85% of which passes a 100-mesh sieve and the whole of which passes a 30-mesh.

"An apparent defect in this specification is the lack of any requirement as to grading of the stone. It is evident that the composition of the mixture might vary within wide limits. However, from Table I, showing the average of the tests of the mixtures actually laid in five working seasons, it will be seen that the aggregate runs fairly uniform. The sand is tested before use for compliance with the specification for that material but no attempt is made at selection, or separation or grading of any sort of the run-of-crusher stone. The material below the 8-mesh is fairly uniform, due no doubt to the sand entering into this part of the mixture. The increase in material passing 100-mesh from 1910 to 1911 is due to a change in specifications increasing the amount of mineral dust. In the 1910 mixture only about 1% of dust was added, whereas not less than 5% has been used since."

Table I.—Average Grading of Bituminous Concrete Mixtures, Washington, D. C., 1910–1914

	1910	1911	1912	1913	1914
Passing 100-mesh sieve	3.2%	7.8%	6.3%	8.0%	8.8%
Passing 80-mesh sieve	1.6%	1.7%	1.2%	1.0%	0.8%
Passing 60-mesh sieve	6.2%	3.6%	3.5%	3.2%	3.2%
Passing 40-mesh sieve	10.7%	7.0%	7.0%	6.1%	5.8%
Passing 20-mesh sieve	10.7%	6.6%	8.0%	13.0%	12.3%
Passing 10-mesh sieve	1.3%	3.0%	4.9%	10.2%	8.0%
Passing 8-mesh sieve	0.3%	1.0%	1.3%	3.8%	2.8%
Passing 4-mesh sieve	2.6%	9.6%	9.5%	17.0%	14.5%
Passing ½-in screen	19.2%	21.2%	26.3%	19.2%	25.2%
Passing ¾-in screen	30.0%	18.0%	18.7%	13.7%	17.6%
Passing 1-in screen	13.0%	20.2%	12.8%	5.0%	0.0%
Passing 1¼-in screen	1.0%	0.0%	0.3%	0.0%	0.0%
Specific gravity of stone	2.85	....	2.93	2.97	2.86
Specific gravity of sand	2.69	....	2.70	2.70	2.68
Percentage of voids in aggregate	26.40	....	21.98	20.76	21.39
Percentage bitumen soluble in CS_2	7.10	6.80	6.90	7.35	6.80

7. Mineral Aggregates for Class C Pavements

Class C bituminous concrete aggregates consist of predetermined mechanically graded broken stone, broken slag, gravel or shell, with or without sand, Portland cement, fine inert material, or combinations thereof.

Broken Stone, Broken Slag and Gravel. For discussion of essential physical properties, see Art. 5.

Sand and Filler. For discussion of different kinds of sands and fillers and the essential physical properties thereof, see Art. 6 and Sect. 17, Arts. 4 and 5.

Composition of Topeka Aggregates. The conclusions of the Spec. Com. Mat. Road Cons., Am. Soc. C. E. (17e) are as follows:

"If the Topeka pavement specification embodies the grading, as contained in the decree of 1910, namely:

Bitumen, from 7 to 11%;
Passing 200-mesh sieve, from 5 to 11%
Passing 40-mesh sieve, from 18 to 30%
Passing 10-mesh sieve, from 25 to 35%
Passing 4-mesh sieve, from 8 to 22%
Passing 2-mesh sieve, less than 10%

special provisions should be made in the specifications covering the broken stone and sand to be used, in order to secure satisfactory grading."

The above recommendations relative to the necessity of more definitely specifying the composition of Topeka aggregates are based on the wide range of combinations of broken stone and sand, or similar materials, which may be used under the 1910 decree formula and the fact that many failures have resulted from the use of poorly graded mixtures. Three forms of specifications covering the Topeka mineral aggregates have been used successfully.

1. The grading of the broken stone and sand have each been covered by specific requirements and the mixed aggregate required to comply with 1910 formula. As an example, the following specifications are quoted, in part. The broken stone shall pass a ½-in screen and shall be so graded that when combined in a bituminous mixture containing not less than 30% of the sand hereafter specified shall produce a bituminous mixture complying with the 1910 decree formula. All particles of the sand shall pass a 10-mesh sieve, and shall contain at least 15% of material retained on a 40-mesh sieve and at least 20% of material that will pass an 80-mesh sieve except as hereinafter provided for. If the sand does not contain the required amount of fine material, mineral dust may be added to make up the deficiency.

2. The broken stone and sand have been covered by general requirements and the mixed aggregate by more detailed requirements than embodied in the 1910 decree formula. This type of specification was adopted by the Am. Soc. Mun. Imp., see Art. 8.

3. Each of the items, broken stone, sand, and mixed aggregate, has been covered by specific requirements, as in the case of U. S. O. P .R. specifications, see Art. 8.

Topeka Pavements as Laid on Riverside Drive, New York, and in Rochester, N. Y. by Richardson (57b). "A fine asphaltic concrete surface was laid on Riverside Drive in New York in the autumn of 1913, data in regard to which are shown in Table II, in which column A gives the average composition of the surface mixture as laid on the street, and column B that of the finer portion, excluding the particles of 4 and 2-mesh size and the bitumen, 4%, which is regarded as sufficient to cover them.

Table II.—Proportions in Asphaltic Concrete Surface on Riverside Drive, New York

Composition			A	B
Asphalt cement	110 lb	Bitumen	8.9%	11.1%
Portland cement dust	110 lb	200-mesh	11.9%	16.5%
Sand	312 lb	80-mesh	14.5%	20.1%
Stone screenings	564 lb	40-mesh	18.6%	25.9%
		10-mesh	18.9%	26.4%
	1096 lb	4-mesh	19.1%	......
		2-mesh	8.1%	......
			100.0%	100.0%

"These figures demonstrate what the character of the finer portion of the mixture may be regarded as a sheet-asphalt surface, to which the stone or grit size has been added. It is seen that this is very satisfactory from that point of view, containing a proper percentage of bitumen and filler, altho the material passing a 10, 20 and 30-mesh sieve is high. It is to be noted that the mixture is much improved by the fact that the filler was Portland cement. It seems reasonable to believe that this surface may be regarded as the highest type of one that is stone-filled or known as fine asphaltic concrete. The results developed by service tests will be of interest.

"In this connection it is worthy of observation that a mixture of this type is being laid in Rochester, N. Y., at the present time (1914), and has been so used for 12 years. The Rochester mixture closely resembles that on Riverside Drive, containing Portland cement as a filler, and has proved itself by service tests, since the date given, to be entirely satisfactory. This mixture has the composition shown in Table III.

Table III.—Mixture Used at Rochester, N. Y.

Composition	Original Mixture	Finer Portion
Bitumen	8.9%	11.1%
200-mesh	12.3%	17.1%
100 and 80-mesh	10.8%	15.0%
50 and 40-mesh	24.2%	33.7%
30, 20 and 10-mesh	16.3%	22.7%
4-mesh	21.5%	......
2-mesh	5.4%	......
	99.4%	99.6%"

Composition of Patented Bituminous Concrete Pavement Aggregates. The conclusions of the Spec. Com. Mat. Road Cons., Am. Soc. C. E. (17e) are as follows: "In cases where patented bituminous concrete pavements of Class C are used, the same fundamental principles observed under Class A pavements should be followed, especially in the case of covering in detail the composition and grading of the mineral aggregate." The following specification, as used by a state highway department to cover the mineral aggregate of a patented pavement, illustrates the indefinite requirements condemned by the committee of the Am. Soc. C. E. "The several grades and sizes of mineral aggregate shall be accurately measured in proportions previously determined by laboratory tests to give the best results, that is, the most dense mixture of mineral aggregate and one having inherent stability." The use of the above form of general descriptive specification allows the contractor to furnish an aggregate which may vary in composition between wide limits. Definite specifications which will control the character

and uniformity of the aggregate of any patented bituminous concrete pavement can be prepared to cover any local conditions. For examples of definite requirements covering aggregates of patented pavements, see the Bithulithic specifications of Los Angeles, Cal., Art. 8; the Bitulithic specifications of Portland, Ore., Art. 16; and the Penn. State Highway Dept. Warrenite specifications, Art. 8.

Differentiation of Bitulithic and Warrenite bituminous concrete mixtures. The following statement was prepared by George C. Warren, President of the Warren Brothers Co., for the information of the engineers enrolled in the Graduate Course in Highway Engineering at Columbia University.

"Bitulithic and Warrenite mixtures are both made under the provisions of the Warren patents, which the courts have held 'cover the product no matter how produced.' Bitulithic is designed to meet the conditions generally prevailing on city streets, and Warrenite is to meet such conditions as may arise on country roads so as to meet the physical and economic conditions and public demands as to cost.

"Generally speaking, Bitulithic is mixed by a plant which is too cumbersome to meet country road conditions, which provides for combining the materials proportioned by separation of sizes of the aggregate, after heating, and then recombining by weight. Warrenite is, generally speaking, mixed by a plant so portable that it may be set up either alongside the railroad, along the side of the road being constructed, or in the quarry or gravel bank from which the bulk of the aggregate is being procured, as may be most economical in any particular case. This plant is constructed on the principle of proportioning the several separate sizes by careful measurement by bulk before heating and retaining the batch so measured as a separate entity thru the process of heating and delivery into the mixer in which the bituminous cement is added.

"Generally speaking, crushed stone predominates in the fine aggregate of Bitulithic, while sand predominates in the fine aggregate of Warrenite; also, fine crushed stone and sand respectively are correspondingly used for the seal coat aggregate. In the selection of quality of material, whether gravel or crushed stone, for the coarse aggregate a greater latitude is permitted in the case of Warrenite to practically meet the conditions of less opportunity for selections which are liable to prevail in localities a considerable distance from railroad centers. This latitude is allowed, because, while the traffic conditions on country road thorofares are in point of weight and concentration of traffic rapidly becoming fully as severe as on most city streets, there is the important difference that on country roads generally the traffic is more exclusively of the motor vehicle rubber tire type and consequently less exaction in physical properties of the quality of the stone forming the basis of the aggregate is necessary. Also, unfortunately, many city streets are abused by constant excessive sprinkling or daily scoured by pressure flushing machines, a practice which is more or less injurious to any road surface, while the country roads are seldom, if ever, wet except by rainfall; therefore, in cases where the very best quality of stone is unavailable, it would be safe to use stone of slightly lower quality in Warrenite on a country road, altho the same quality stone might not be safe for use in Bitulithic on a city street."

8. Specifications for Mineral Aggregates

Class A. Am. Soc. Mun. Imp. 1917 Specifications for Broken Stone Aggregate are as follows:

"**Quality.** All broken stone shall be clean, rough-surfaced and sharp-angled, of compact texture and uniform grain.

"**Tests.** The broken stone shall be subjected to abrasion and toughness tests conducted by the engineer in accordance with methods adopted by the Am. Soc. Test. Mat., Aug. 15, 1908. The broken stone used for the construction of the wearing course shall show a loss on abrasion of not more than 3.5% or a French coefficient of wear of not less than 11.5, and its toughness shall not be less 13.0.

"**Broken Stone for Mineral Aggregate.** Broken stone for the mineral aggregate of the wearing course shall consist of one product of a stone crushing and screening plant. It shall conform to the following mechanical analysis, using laboratory screens having circular openings: All of the broken stone shall pass a 1¼-in screen; not

more than 10% nor less than 1% shall be retained upon a 1-in screen; not more than 10% nor less than 3% shall pass a ¼-in screen."

Class A. U. S. O. P. R. 1918 Specifications for Broken Stone Aggregate are as follows:

"**General.** The broken stone shall consist of angular fragments of rock, excluding schist, shale and slate, free from thin or elongated pieces, soft or disintegrated stone, dirt or other objectionable matter, occurring either free or as a coating on the stone.

"**Physical Properties.** The stone shall meet the following requirements: French coefficient of wear, not less than 8; toughness, not less than 8.

"**Chips.** That portion of the product of the crusher which, when tested by means of laboratory screens, will meet the following requirements:

Passing ½-in screen, not less than	95%
Retained on ¼-in screen, not less than	85%

"**Aggregate.** That portion of the product of the crusher, which, when tested by means of laboratory screens, will meet the following requirements:

Passing 1-in screen, not less than	95%
Total passing ¾-in screen	25 to 75%
Retained on ½-in screen, not less than	85%

"**Methods of Testing.** Tests of the physical properties of the rock and of the sizes of broken stone products shall be made in accordance with the following methods:

1. French Coefficient of Wear: Bul. U. S. Dept. Agr., 347, p. 5.
2. Toughness: Bul. U. S. Dept. Agr., 347, p. 15.
3. Size: Bul. U. S. Dept. Agr., 555, p. 32.

"**Notes:** This specification is intended to cover stone to be used in the construction of a bituminous concrete wearing course and seal coat. The broken stone aggregate for the concrete proper is a single size of crusher product with no exact grading limitations. It may, therefore, produce what is commonly known as an open mix, and will carry from 5 to 7% bitumen. Such mixture may be placed on a well compacted broken stone or gravel foundation or a cement-concrete foundation so as to produce, after rolling, a wearing course 2 in in depth. A seal coat of bituminous material should then be applied and covered with chips in sufficient quantity to take up all excess of bitumen."

Class B. U. S. O. P. R. 1918 Specifications for Mineral Aggregate of Broken Stone, Sand and Filler are as follows:

"**Broken Stone.** GENERAL. The broken stone shall consist of angular fragments of rock, excluding schist, shale, and slate, free from thin or elongated pieces, soft or disintegrated stone, dirt or other objectionable matter, occurring either free or as a coating on the stone.

"PHYSICAL PROPERTIES. The stone shall meet the following requirements: French coefficient of wear, not less than 8; toughness, not less than 8.

"CHIPS. That portion of the product of the crusher which, when tested by means of laboratory screens, will meet the following requirements:

Passing ½-in screen, not less than	95%
Retained on ¼-in screen, not less than	85%

"COARSE AGGREGATE. That portion of the crusher which, when tested by means of laboratory screens, will meet the following requirements:

Passing 1-in screen, not less than	95%
Total passing ¾-in screen	25 to 75%
Retained on ½-in screen, not less than	85%

"**Sand.** GENERAL. The sand for fine aggregate shall be composed of sound, durable stone particles, free from a coating of clay or loam.

"GRADING. When tested by means of laboratory screens and sieves, the sand shall meet the following requirements:

Passing ¼-in screen	100%
Total passing 40-mesh sieve	30 to 70%
Retained on 200-mesh, not less than	90%

"**Mineral Filler.** GENERAL. The mineral filler shall consist of limestone dust, dolomite dust, Portland cement or natural cement. It shall be free from foreign or other objectionable material.

"FINENESS. When tested by means of laboratory sieves, the mineral filler shall meet the following requirements:

Passing 30-mesh sieve 100%
Total passing 200-mesh sieve, not less than 65%

"**Methods of Testing.** Tests of the physical properties of the rock and of the size or mechanical analysis of broken stone, sand and mineral filler shall be made in accordance with the following methods:

1. French Coefficient of Wear: Bul. U. S. Dept. Agr., 347, p. 5.
2. Toughness: Bul. U. S. Dept. Agr., 347, p. 15.
3. Size of Broken Stone: Bul. U. S. Dept. Agr., 555, p. 32.
4. Mechanical Analysis of Sand and Mineral Filler: Bul. U. S. Dept. Agr., 555, p. 33.

"**Notes:** This specification is intended to cover the mineral constituents of a roughly proportioned bituminous concrete consisting of from 45 to 60% broken stone coarse aggregate, from 30 to 45% sand or fine aggregate, from 3 to 5% mineral filler, and from 5 to 8% bitumen. It should preferably be placed upon a cement-concrete foundation so as to produce, after rolling, a wearing course 2 in in depth. A seal coat of bituminous material should then be applied and covered with chips in sufficient quantity to take up all excess of bitumen."

Class B. Cleveland, 1917 Specifications for an Aggregate of Broken Stone, Sand and Dust.

"**Description.** The mineral aggregate shall consist of a mixture of broken Bessemer limestone, or other limestone equally as good, trap rock or granite, and sand, to which shall be added a small quantity of stone dust or Portland cement.

"**Sizes.** The stone shall vary in size from that passing a 1¼-in screen to as small as that held on a ¼-in screen. The dust or fine screenings shall be removed from the stone.

"The sand shall be hard-grained, moderately sharp, free from loam or other foreign material and varying in size from that passing a ¼-in screen to dust passing a 200-mesh sieve. There shall not be over 5% passing the 200-mesh sieve and there shall not be over 30% held on the 10-mesh sieve.

"The dust which shall be added to the mixtures shall be either a Portland cement or ground limestone.

"The Proportions of the various ingredients composing the bituminous concrete shall be approximately 3 parts of stone to 2 parts of sand, to which shall be added bituminous cement sufficient so that from 7 to 10% by weight of the mixture shall be bitumen soluble in carbon disulphide. The stone dust or Portland cement added to the mixture shall be in such quantities that a screening of the whole aggregate shall not show more than 6% by weight passing a 200-mesh sieve."

Class C. Form of Specifications for Topeka Coarse and Fine Aggregates adopted at the first conference of State Highway Testing Engineers and Chemists held at the U. S. O. P. R. in Feb., 1917 (67c):

"**Coarse Aggregate.** GENERAL. The broken stone for coarse aggregate shall consist of angular fragments of (insert types allowable), free from thin or elongated pieces, soft or disintegrated stone, dirt, or other objectionable matter, occurring either free or as a coating on the stone.

"PHYSICAL PROPERTIES. The stone shall meet the following requirements:

Percent of wear .... not more than ....
or French coefficient .... not less than ....
*Hardness .... not less than ....
*Toughness .... not less than ....
*Absorption .... not more than ....

"GRADING. The broken stone for coarse aggregate, when tested by means of laboratory screens, shall meet the following requirements:

Passing (the largest size selected) .. in screen 100%
Passing (the largest size selected) .. in screen and retained on (the second largest size selected) .. in screen .... % to .... %
†Passing, etc, ...

* Tests recommended by the conference, which it may be desirable to omit in some instances.

† The number and sizes of screens may be continued as desired by the engineer. The last requirement should be:
Passing 10-mesh sieve .... not more than ...... %.

"METHOD OF SAMPLING. Stone shall be sampled for quality and grading in accordance with the method described on page ...., paragraphs ...., of these specifications.

"METHODS OF TESTING. Tests of the physical properties and grading of the stone shall be made in accordance with the methods described on pages .... of these specifications, tests Nos. ....

"Fine Aggregate. GENERAL. The fine aggregate shall be composed of sound, durable particles of stone or sand. The particles shall be free from a coating of clay or loam.

"GRADING. The broken stone or sand for fine aggregate, when tested by means of laboratory sieves, shall meet the following requirements:

Passing 10-mesh sieve............................	not less than...%
Passing 10-mesh and retained on 40-mesh sieve.......	% to.......%
Passing 40-mesh and retained on 80-mesh sieve.......	% to.......%
Passing 80-mesh and retained on 200-mesh sieve.......	% to.......%
Passing 200-mesh sieve............................	% to.......%."

Class C. Am. Soc. Mun. Imp. Specifications for Topeka Mineral Aggregate, as adopted in 1916, are as follows:

"General. The mineral aggregate shall consist of a mixture of broken stone and sand, to which shall be added as required, stone dust or Portland cement.

"Broken Stone. Any sound, durable stone, either trap rock, limestone or granite, usually considered suitable for macadam, may be used. It should be broken as nearly cubical as practicable. It should not show distinct planes of cleavage or crystalline faces and should not readily crush or split under the roller when being rolled in the pavement. Between two kinds of stone, choice should generally be made of the one showing the greater toughness rather than hardness. A certain percentage of absorption, such as is shown by the better grades of limestone, is a desirable quality, as the bonding strength of the cement is somewhat improved thereby.

"The Sand shall be hard-grained, moderately sharp, free from loam or other foreign material and varying in size from that passing a ¼-in screen to dust passing a 200-mesh sieve, and there should not be over 10% held on the 10-mesh sieve, nor over 5% passing the 200-mesh sieve.

"Dust in the form of finely ground stone or Portland cement may be added to the mixture, but in such quantities that the screenings of the total ingredients entering into the mix shall in no case show over 10% by weight passing a 200-mesh sieve.

"The Proportions of the various ingredients composing the bituminous concrete shall be as follows:

Bitumen..	7 to 9%
Passing 200-mesh sieve............................	7 to 10%
Passing 80-mesh sieve, but retained on a 200.............	10 to 20%
Passing 40-mesh sieve, but retained on an 80.............	10 to 25%
Passing 20-mesh sieve, but retained on a 40.............	10 to 25%
Passing 8-mesh sieve, but retained on a 20.............	10 to 20%
Passing 4-mesh sieve, but retained on an 8.............	15 to 20%
Passing 2-mesh sieve, but retained on a 4.............	5 to 10%

"The minimum amount of bitumen allowed shall be used only in mixtures containing the minimum total passing the 80-mesh. The percentage of bitumen must be increased above the minimum as the total passing the 80-mesh increases.

"The item designated as dust includes, in addition to the stone dust or Portland cement that may be added, such fine sand passing a 200-mesh sieve as may be found self-contained in the sand to be used, and such 200-mesh mineral as may be self-contained in the refined asphalt."

Class C. U. S. O. P. R. 1918 Specifications for Modified Topeka Aggregate are as follows:

"Broken Stone. GENERAL. The broken stone shall consist of angular fragments of rock, excluding schist, shale and slate, free from thin or elongated pieces, soft or disintegrated stone, dirt, or other objectionable matter, occurring either free or as a coating on the stone.

"SIZE. It shall be that product of the crusher which, when tested by means of laboratory screens, will meet the following requirements:

Passing ½-in screen, not less than	95%
Retained on ¼-in screen, not less than	20%

"**Sand.** GENERAL. The sand shall be composed of sound, durable stone particles, free from a coating of clay or loam.

"SIZE. When tested by means of laboratory screens and sieves, the sand shall meet the following requirements:

Passing ¼-in screen	100%
Retained on 200-mesh sieve, not less than	90%

"**Mineral Filler.** GENERAL. The mineral filler shall consist of limestone dust, dolomite dust, Portland cement, or natural cement. It shall be free from foreign or other objectionable material.

"FINENESS. When tested by means of laboratory sieves, the mineral filler shall meet the following requirements:

Passing 30-mesh sieve	100%
Total passing 200-mesh sieve, not less than	65%

"**Total Mineral Aggregate.** GENERAL. The total mineral aggregate shall consist of a uniform mixture of the broken stone, sand and mineral filler, the required grading of each being such as to produce, when properly proportioned, a mixture conforming to the following limitations for grading. The exact proportion of each constituent producing a total mineral aggregate within these limitations shall be as directed by the engineer.

"GRADING. When tested by means of laboratory screens and sieves, the total mineral aggregate shall meet the following requirements:

Passing ½-in screen and retained on ¼-in screen	5 to 10%
Passing ¼-in screen and retained on 10-mesh sieve	11 to 25%
Passing 10-mesh sieve and retained on 40-mesh sieve	7 to 25%
Passing 40-mesh sieve and retained on 80-mesh sieve	11 to 36%
Passing 80-mesh sieve and retained on 200-mesh sieve	10 to 25%
Passing 200-mesh sieve	5 to 11%

"**Methods of Testing.** Tests of the size or mechanical analysis of broken stone, sand, and mineral filler shall be made in accordance with the following methods:

1. Size of Broken Stone: Bul. U. S. Dept. Agr., 555, p. 32.
2. Mechanical Analysis of Sand and Mineral Filler: Bul. U. S. Dept. Agr., 555, p. 33.
3. Grading of Total Mineral Aggregate: Bul. U. S. Dept. Agr., 555, pp. 32 and 33.

"**Notes:** This specification is intended to cover the mineral constituents and grading for bituminous concrete of a modified Topeka, or stone-filled sheet-asphalt type. It is so drawn that from 10 to 50% of broken stone will be required and the mixture of very fine broken stone and sand will possess a satisfactory sheet-asphalt grading. Such an aggregate will carry from 7 to 11% of bitumen. It should preferably be placed upon a cement-concrete foundation to a compacted depth of 2 in. No seal coat will ordinarily be required."

Class C. Penn. State Highway Dept. 1917 Specifications for Warrenite Mineral Aggregate.

"The Warrenite surface paving mixture shall consist of approved crushed stone, with or without the addition of sand, graded in the following proportions so as to give the wearing surface a useful degree of density, rigidity, inherent stability and freedom from voids:

Material passing a 1¼-in screen and retained on a 2-mesh sieve	40 to 60%
Material passing a 2-mesh sieve and retained on a 4-mesh sieve	10 to 20%
Material passing a 4-mesh sieve and retained on a 10-mesh sieve	10 to 5%
Material passing a 10-mesh sieve and retained on a 30-mesh sieve	10 to 5%
Material passing a 80-mesh sieve, at least 25% of which will pass a 200-mesh sieve	10 to 5%

"The balance to pass a 30-mesh sieve and be retained on a 60-mesh sieve."

Class C. Los Angeles, Cal., 1917 Specifications for Bitulithic Mineral Aggregate.

"Upon the foundation, previously prepared and thoroly swept free from all rubbish, shall be laid the Bitulithic wearing surface composed of a mixture of broken stone, sand, stone dust and Bitulithic Waterproof Cement, in sufficient quantities to make the mixture conform to the following proportions by weight:

Passing 1½-in screen and retained on a 1-in screen......	**10 to 15%**
Passing 1-in screen and retained on a ½-in screen.....	**25 to 35%**
Passing ½-in screen and retained on a ¼-in screen.....	**12 to 20%**
Passing ¼-in screen and retained on a 10-mesh sieve....	**8 to 12%**
Passing a 10-mesh and retained on a 200-mesh sieve......	**24 to 32%**
Passing a 200-mesh sieve............................	**4 to 7%**
Bitulithic Waterproof Cement........................	**7 to 9.5%**

"From 60% to 80% of the aggregate passing a 10-mesh sieve shall pass a 40-mesh sieve and from 15 to 30% of the sand shall pass an 80-mesh sieve."

For additional specifications for mineral aggregates of bituminous concretes of Classes A, B, and C, see Arts. 13, 15 and 17, respectively.

9. Bituminous Cements

The bituminous cements which have been used successfully in the construction of bituminous concrete pavements include asphalt, water-gas tar and coal tar cements, and cements which are combinations of refined tars, and combinations of refined tars and asphalts.

Bituminous Cements for Class A Aggregates. All of the types of bituminous cements enumerated have been used in the construction of Class A pavements. If unheated aggregate is used, very good results have been obtained with all the different types except asphalt cements. With unheated road metal it is not usually practicable to coat the unheated aggregate with the most efficacious grades of asphalt cement. For light traffic highways, however, successful results have been secured by using a cut-back asphalt cement. Except for the so-called cold patching methods used in maintenance work, heated aggregates should always be used if machine mixing methods are employed, thus permitting the use of the most suitable types and grades of bituminous cements.

Bituminous Cements for Seal Coats of Class A Pavements. Conclusions, Spec. Com. Mat. Road Cons., Am. Soc. C. E. (17e). "Experience has demonstrated that the most efficacious bituminous concrete pavements of Class A are constructed by using suitable asphalt cements or refined tars in the mix, and asphalt cements for seal coats. Satisfactory results will be secured when tar cements are used for seal coats, but the surface must be retreated more frequently than when asphalt cements are used."

Results of Rhode Island and New York City Service Tests with Seal Coats. In 1909 a series of service test sections was constructed on a Rhode Island state road subjected to mixed traffic of about 100 horse-drawn vehicles and from 250 to 300 motor-cars per day, many of the motor-vehicles being of the large touring-car type and traveling at high speeds. These experimental sections were constructed to determine the most economical and satisfactory bituminous material to be used for the cement in the mix and for the seal coat for bituminous concrete pavements subjected to the above class of traffic. Asphalt cement, refined water-gas tar, refined coal tar and combinations of refined coal tar and asphalt were employed in the construction of the sections. In each section, the same material was used for the binder and the seal coat, except in one section in which coal tar was used in the mix and asphalt cement for the seal coat. The results secured from these experiments, based upon an examination in 1912, indicate that for this class of combination traffic or for horse-drawn vehicle or iron-

tired traffic exclusively, the seal coat generally should consist of an asphalt cement, as being more economical and efficacious than refined tar, or a combination of refined tar and asphalt. I. W. Patterson, Chief Engineer, State Board of Public Roads of Rhode Island, states (53a), as a result of investigations made in 1914, that " it was shown conclusively that a seal coat of asphalt is much more permanent than a seal coat of refined tar, altho the refined tars gave excellent results as far as their binding of the mineral aggregate was concerned.

The same conclusion has been reached as the results of service test sections constructed in the Borough of Queens, New York City, in 1911. In this instance a bituminous concrete, with tar used as the cement and seal coat, required retreatment with a seal coat in 1912, while the section constructed with tar cement in the mix and an asphalt cement as the seal coat did not require a new seal coat when inspected in 1916. See Art. 23 for record of maintenance and traffic data pertaining to the Borough of Queens sections.

Bituminous Cements for Classes B and C Pavements. Asphalt and tar cements have been used in the construction of most of the types of Class B and Class C pavements since 1910. Variation in practice is well illustrated by the use of both tars and asphalt cements in the construction of Topeka pavements. Tar concrete pavements, similar in composition to the Topeka pavement were constructed in Washington, D. C., Pittsburgh, Pa. and the New England states between 1870 and 1895. After the 1910 decree was announced, practically all Topeka pavements were constructed with asphalt cements due, without doubt, to its similarity, in part, to the sheet-asphalt pavement. Since 1913, tar cements have been used in the construction of Topeka pavements in several cities of the Middle West and also in cities of New England, and in 1916 the Am. Soc. Mun. Imp. incorporated alternate specifications for asphalt and tar cements in its Topeka pavement specifications.

Bitumen Content in Wearing Course Mixtures. In specifications and records of work the bitumen content of bituminous concretes is expressed in one of two ways: First, as the number of gallons per square yard or cubic yard of mineral aggregate; and, secondly, as a certain percentage by weight of the wearing course mixture. The latter method is more accurate and definite, and is generally employed. It is apparent that the amount of bituminous cement used by the second method materially depends upon the specific gravities of both the mineral aggregate and the bituminous cement, see Sect. 12, Art. 44.

Forms of Reports for Bituminous Cements. See Sect. 15, Art. 7.

Sources, Manufacture, Physical and Chemical Properties, Tests, Transportation, Storage, and Inspection of Bituminous Materials. See Sect. 12.

Toughness of Bituminous Aggregates. Reeve and Lewis (56) have drawn the following conclusions from concurrent field and laboratory investigations; using standard toughness cylinders composed of 8 to 50-mesh rock mineral aggregates and bituminous cements, which were tested in a Page impact machine with a 500-g hammer. "(1) The toughness of bituminous aggregates in which a given bituminous material is used will not be the same for every type of rock. (2) Tests of laboratory specimens can be directly correlated with results in service. (3) The difference in behavior of the various rock types can not be directly attributed to any of the routine physical test values of the rock, but appears to be due largely to differences in the surface character of the rock particles. (4) While relatively soft or fluid bitumens may yield satisfactory results in bituminous concrete with some types of rock, their use with other types will lead to failure of the road surface. (5) The impact or toughness test of bituminous aggregates offers possibilities as a means of determining in advance the relative behavior in service of bituminous concretes."

10. Specifications for Bituminous Cements

Am. Soc. Mun. Imp. 1917 Specifications for Bituminous Cements to be Used with a Mineral Aggregate Consisting of One Product of a Stone Crushing and Screening Plant:

"General. The asphalt cement or refined tar used in the construction of the wearing course of the bituminous concrete pavement shall conform with either one of the specifications covering the chemical and physical properties of bituminous cements designated Asphalt Cement A, B, C, D and E, and Refined Tar F and G. If asphalt cement is used in the bituminous concrete wearing course, the same asphalt cement shall be used for the seal coat. If refined tar is used in the bituminous concrete wearing course, an asphalt cement shall be used in the seal coat and shall conform with either one of the specifications covering the physical and chemical properties of asphalt cements, designated Asphalt Cement H, K and L.

"Previous Service. The contractor will be required to show, to the satisfaction of the engineer, that the company manufacturing the asphalt cement or refined tar he proposes to use under a given specification has, for a period of at least 2 years, manufactured asphalt cement or refined tar in a thoroly equipped plant, and that asphalt cement or refined tar manufactured of bituminous material obtained from a similar source to that which he proposes to use, shall have been in continuous and successful use for a period of at least 2 years in bituminous pavements constructed by the mixing method previous to the date of the letting in which his proposal was submitted.

"Asphalt Cement A optional with asphalt cements B, C, D, E, and refined tars F and G.

1. The asphalt cement shall be homogeneous, free from water and shall not foam when heated to 177° C (350° F).

2. It shall show a flash point of not less than 205° C (400° F).

3. Its specific gravity at a temperature of 25° C (77° F) shall be not less than 0.970 nor more than 1.000.

4. When tested with a standard No. 2 needle by means of a Dow penetrometer, or other penetrometer giving the same results as the Dow machine, it shall show penetrations within the following limits for the conditions stated, the penetrations being expressed in hundredths of a centimeter: 100 g load, 5 sec, at 25° C (77° F), from 75 to 90; 200 g load, 1 min, at 4° C (39° F), not less than 35; 50 g load, 5 sec, at 46° C (115° F), not more than 250.

5. Its melting point as determined by the cube method shall be not less than 55° C (131° F).

6. When 50 g of the material is maintained at a uniform temperature of 163° C (325° F) for 5 hr in an open cylindrical tin dish, 5½ cm (about 2¼ in) in diameter, with vertical sides measuring approximately 3½ cm (about 1⅓ in) in depth, the loss in weight shall not exceed 1% of the original weight of the sample.

The penetration of the residue, when tested as described in clause (4) with a standard No. 2 needle under a load of 100 g, for 5 sec at 25° C (77° F) shall be not less than one-half the penetration of the original material tested under the same conditions.

7. Its bitumen as determined by its solubility in chemically pure carbon disulphide at room temperature shall not be less than 99.5%.

8. It shall be soluble in chemically pure carbon tetrachloride at room temperature to the extent of not less than 99.5% of its bitumen as determined by clause (7).

9. It shall be soluble in 86° to 88° B paraffin naphtha, at least 85% distilling between 40° and 55° C (104° and 131° F), to the extent of not less than 70% nor more than 80% of its bitumen as determined by clause (7).

10. It shall yield not less than 8% nor more than 12% of fixed carbon.

"Asphalt Cement B optional with asphalt cements A, C, D, E, and refined tars F and G.

1. The asphalt cement shall be homogeneous, free from water and shall not foam when heated to 177° C (350° F).

2. It shall show a flash point of not less than 205° C (400° F).

3. Its specific gravity at a temperature of 25° C (77° F) shall be not less than 1.000 nor more than 1.030.

4. When tested with a standard No. 2 needle by means of a Dow penetrometer, or other penetrometer giving the same results as the Dow machine, it shall show penetrations within the following limits for the conditions stated, the penetrations being expressed in hundredths of a centimeter: 100 g load, 5 sec, at 25° C (77° F), from 90 to 100; 200 g load, 1 min, at 4° C (39° F), not less than 30.

5. Its melting point as determined by the cube method shall be not less than 50° C (122° F).

6. When 50 g of the material is maintained at a uniform temperature of 163° C (325° F) for 5 hr in an open cylindrical tin dish, 5½ cm (about 2¼ in) in diameter, with vertical sides measuring approximately 3½ cm (about 1½ in) in depth, the loss in weight shall not exceed 1% of the original weight of the sample.

The penetration of the residue, when tested as described in clause 4 with a standard No. 2 needle under a load of 100 g, for 5 sec at 25° C (77° F) shall be not less than one-half the penetration of the original material tested under the same conditions.

7. Its bitumen as etermined by its solubility in chemically pure carbon disulphide at room temperature shall not be less than 99.5%.

8. It shall be soluble in chemically pure carbon tetrachloride at room temperature to the extent of not less than 99.5% of its bitumen as determined by clause (7).

9. It shall be soluble in 86° to 88° B paraffin naphtha, at least 85% distilling between 40° and 55° C (104° and 131° F), to the extent of not less than 72% nor more than 78% of its bitumen as determined by clause (7).

10. It shall yield not less than 11% nor more than 15% of fixed carbon.

"Asphalt Cement C optional with asphalt cements A, B, D, E, and refined tars F and G.

1. The asphalt cement shall be homogeneous, free from water and shall not foam when heated to 177° C (350° F).

2. It shall show a flash point of not less than 205° C (400° F).

3. Its specific gravity at a temperature of 25° C (77° F) shall be not less than 1.030 nor more than 1.040.

4. When tested with a standard No. 2 needle by means of a Dow penetrometer, or other penetrometer giving the same results as the Dow machine, it shall show penetrations within the following limits for the conditions stated, the penetrations being expressed in hundredths of a centimeter: 100 g load, 5 sec, at 25° C (77° F), from 70 to 90; 200 g load, 1 min, at 4° C (39° F), not less than 10.

5. Its melting point as determined by the cube method shall be not less than 45° C (113° F).

6. When 50 g of the material is maintained at a uniform temperature of 163° C (325° F) for 5 hr in an open cylindrical tin dish, 5½ cm (about 2¼ in) in diameter, with vertical sides measuring approximately 3½ cm (about 1½ in) in depth, the loss in weight shall not exceed 2% of the original weight of the sample.

The penetration of the residue, when tested as described in clause (4) with a standard No. 2 needle under a load of 100 g, for 5 sec at 25° C (77° F) shall not be less than one-half the penetration of the original material tested under the same conditions.

7. Its bitumen as determined by its solubility in chemically pure carbon disulphide at room temperature shall not be less than 99.5%.

8. It shall be soluble in chemically pure carbon tetrachloride at room temperature to the extent of not less than 99.5% of its bitumen as determined by clause (7).

9. It shall be soluble in 86° to 88° B paraffin naphtha, at least 85% distilling between 40° and 55° C (104° and 131° F), to the extent of not less than 80% nor more than 88% of its bitumen as determined by clause (7).

10. It shall yield not less than 10% nor more than 14% of fixed carbon.

"Asphalt Cement D optional with asphalt cements A, B, C, E, and refined tars F and G.

1. The asphalt cement shall be homogeneous, free from water and shall not foam when heated to 177° C (350° F).

2. It shall show a flash point of not less than 205° C (400° F).

3. Its specific gravity at a temperature of 25° C (77° F) shall be not less than 1.025 nor more than 1.050.

4. When tested with a standard No. 2 needle by means of a Dow penetrometer, or other penetrometer giving the same results as the Dow machine, it shall show penetrations within the following limits for the conditions stated, the penetrations

being expressed in hundredths of a centimeter: 100 g load, 5 sec, at 25° C (77° F), from 85 to 95; 200 g load, 1 min, at 4° C (39° F), not less than 20.

5. Its melting point as determined by the cube method shall be not less than 50° C (122° F).

6. When 50 g of the material is maintained at a uniform temperature of 163° C (325° F) for 5 hr in an open cylindrical tin dish, 5½ cm (about 2¼ in) in diameter, with vertical sides measuring approximately 3½ cm (about 1½ in) in depth, the loss in weight shall not exceed 2% of the original weight of the sample.

The penetration of the residue, when tested as described in clause (4) with a standard No. 2 needle under a load of 100 g, for 5 sec at 25° C (77° F) shall be not less than one-half the penetration of the original material tested under the same conditions.

7. Its bitumen as determined by its solubility in chemically pure carbon disulphide at room temperature shall not be less than 99.5%.

8. It shall be soluble in chemically pure carbon tetrachloride at room temperature to the extent of not less than 99.5% of its bitumen as determined by clause (7).

9. It shall be soluble in 86° to 88° B paraffin naphtha, at least 85% distilling between 40° and 55° C (104° and 131° F), to the extent of not less than 67% nor more than 77% of its bitumen as determined by clause (7).

10. It shall yield not less than 12% nor more than 18% of fixed carbon.

"Asphalt Cement E optional with asphalt cements A, B, C, D, and refined tars F and G.

1. The asphalt cement shall be homogeneous, free from water and shall not foam when heated to 177° C (350° F).

2. It shall show a flash point of not less than 165° C (329° F).

3. Its specific gravity at a temperature of 25° C (77° F) shall be not less than 1.040 nor more than 1.060.

4. When tested with a standard No. 2 needle by means of a Dow penetrometer, or other penetrometer giving the same results as the Dow machine, it shall show penetrations within the following limits for the conditions stated, the penetrations being expressed in hundredths of a centimeter: 100 g load, 5 sec, at 25° C (77° F), from 140 to 160; 200 g load, 1 min, at 4° C (39° F), not less than 40.

5. When tested by means of the New York Testing Laboratory Float Apparatus, the float shall not sink in water maintained at 66° C (150° F) in less than 120 sec nor more than 180 sec.

6. When 50 g of the material is maintained at a uniform temperature of 163° C (325° F) for 5 hr in an open cylindrical tin dish, 5½ cm (about 2¼ in) in diameter with vertical sides measuring approximately 3½ cm (about 1½ in) in depth, the loss in weight shall not exceed 3% of the original weight of the sample.

The penetration of the residue, when tested as described in clause (4) with a standard No. 2 needle under a load of 100 g, for 5 sec at 25° C (77° F) shall be not less than one-half the penetration of the original material tested under the same conditions.

7. Its bitumen as determined by its solubility in chemically pure carbon disulphide at room temperature shall be not less than 93% nor more than 98%.

8. It shall be soluble in chemically pure carbon tetrachloride at room temperature to the extent of not less than 98.5% of its bitumen as determined by clause (7).

9. It shall be soluble in 86° to 88° B paraffin naphtha, at least 85% distilling between 40° and 55° C (104° and 131° F), to the extent of not less than 75% nor more than 85% of its bitumen as determined by clause (7).

10. It shall yield not less than 11% nor more than 15% of fixed carbon.

11. Upon ignition it shall yield not less than 1% nor more than 3% of ash.

"Refined Tar F optional with asphalt cements A, B, C, D, E, and refined tar G.

1. The refined tar shall be homogeneous, free from water and shall not foam when heated to 150° C (302° F).

2. Its specific gravity at a temperature of 25° C (77° F) shall be not less than 1.160 nor more than 1.200.

3. When tested by means of the New York Testing Laboratory Float Apparatus, the float shall not sink in water maintained at 50° C (122° F) in less than 140 sec nor more than 170 sec.

4. Its bitumen as determined by its solubility in chemically pure carbon disulphide at room temperature shall be not less than 95% and it shall show not more than 0.2% ash upon ignition of the material insoluble in carbon disulphide.

5. When distilled according to the tentative method recommended by Com. D-4, Am. Soc. Test. Mat. in 1911, it shall yield no distillate at a temperature lower than 170° C (338° F); not more than 7% by weight shall distill below 270° C (518° F), and not more than 20% by weight shall distill below 300° C (572° F).

6. The total distillate from the test made in accordance with clause (5) shall have a specific gravity at a temperature of 25° C (77° F) of not less than 1.000 nor more than 1.020.

7. The melting point, as determined in water by the cube method, of the pitch residue remaining after distillation to 300° C (572° F), in accordance with the test described in clause (5), shall be not more than 75° C (167° F).

" Refined Tar G optional with asphalt cements A, B, C, D, E, and refined tar F.

1. The refined tar shall be homogeneous, free from water and shall not foam when heated to 150° C (302° F.).

2. Its specific gravity at a temperature of 25° C (77° F) shall be not less than 1.200 nor more than 1.300.

3. When tested by means of the New York Testing Laboratory Float Apparatus, the float shall not sink in water maintained at 50° C (122° F) in less than 140 sec nor more than 170 sec.

4. Its bitumen as determined by its solubility in chemically pure carbon disulphide at room temperature shall not be less than 75% nor more than 90%, and it shall not show more than 0.2% ash upon ignition of the material soluble in carbon disulphide.

5. When distilled according to the tentative method recommended by Com. D-4, Am. Soc. Test. Mat. in 1911, it shall yield no distillate at a temperature lower than 170° C (338° F); not more than 10% by weight shall distill below 270° C (518° F), and not more than 20% by weight shall distill below 300° C (572° F).

6. The total distillate from the test made in accordance with clause (5) shall have a specific gravity at a temperature of 25° C (77° F) of not less than 1.030.

7. The melting point, as determined in water by the cube method, of the pitch residue remaining after distillation to 300° C (572° F), in accordance with the test described in clause (5), shall be not more than 75° C (167° F).

"Asphalt Cement H optional with asphalt cements K and L.

1. The asphalt cement shall be homogeneous, free from water and shall not foam when heated to 177° C (350° F).

2. It shall show a flash point of not less than 205° C (400° F).

3. Its specific gravity at a temperature of 25° C (77° F) shall be not less than 0.970 nor more than 1.000.

4. When tested with a standard No. 2 needle by means of a Dow penetrometer, or other penetrometer giving the same results as the Dow machine, it shall show penetrations within the following limits for the conditions stated, the penetrations being expressed in hundredths of a centimeter: 100 g load, 5 sec, at 25° C (77° F), from 60 to 75; 200 g load, 1 min, at 4° C (39° F), not less than 50; 50 g load, 5 sec, at 46° C (115° F), not more than 150.

5. Its melting point as determined by the cube method shall be not less than 80° C (176° F).

6. When 50 g of the material is maintained at a uniform temperature of 163° C (325° F) for 5 hr in an open cylindrical tin dish, 5½ cm (about 2¼ in) in diameter, with vertical sides measuring approximately 3½ cm (about 1½ in) in depth, the loss in weight shall not exceed 1% of the original weight of the sample.

The penetration of the residue, when tested as described in clause (4) with a standard No. 2 needle under a load of 100 g, for 5 sec at 25° C (77° F) shall be not less than one-half the penetration of the original material tested under the same conditions.

7. Its bitumen as determined by its solubility in chemically pure carbon disulphide at room temperature shall not be less than 99.5%.

8. It shall be soluble in chemically pure carbon tetrachloride at room temperature to the extent of not less than 99.5% of its bitumen as determined by clause (7).

9. It shall be soluble in 86° to 88° B paraffin naphtha, at least 85% distilling between 40° and 55° C (104° and 131° F), to the extent of not less than 70% nor more than 80% of its bitumen as determined by clause (7).

10. It shall yield not less than 8% nor more than 12% of fixed carbon.

"Asphalt Cement K optional with asphalt cements H and L.

1. The asphalt cement shall be homogeneous, free from water and shall not foam when heated to 177° C (350° F).

2. It shall show a flash point of not less than 205° C (400° F).

3. Its specific gravity at a temperature of 25° C (77° F) shall be not less than 1.030 nor more than 1.045.

4. When tested with a standard No. 2 needle by means of a Dow penetrometer, or other penetrometer giving the same results as the Dow machine, it shall show penetrations within the following limits for the conditions stated, the penetrations being expressed in hundredths of a centimeter: 100 g load, 5 sec, at 25° C (77° F), from 60 to 70; 200 g load, 1 min, at 4° C (39° F), not less than 18; 50 g load, 5 sec, at 46° C (115° F), not more than 270.

5. Its melting point as determined by the cube method shall be not less than 60° C (140° F).

6. When 50 g of the material is maintained at a uniform temperature of 163° C (325° F) for 5 hr in an open cylindrical tin dish, 5½ cm (about 2¼ in) in diameter, with vertical sides measuring approximately 3½ cm (about 1½ in) in depth, the loss in weight shall not exceed 1% of the original weight of the sample.

The penetration of the residue, when tested as described in clause (4) with a standard No. 2 needle under a load of 100 g, for 5 sec at 25° C (77° F) shall be not less than one-half the penetration of the original material tested under the same conditions.

7. Its bitumen as determined by its solubility in chemically pure carbon disulphide at room temperature shall not be less than 99.5%.

8. It shall be soluble in chemically pure carbon tetrachloride at room temperature to the extent of not less than 99.5% of its bitumen as determined by clause (7).

9. It shall be soluble in 86° to 88° B paraffin naphtha, at least 85% distilling between 40° and 55° C (104° and 131° F), to the extent of not less than 70% nor more than 80% of the bitumen as determined by clause (7).

10. It shall yield not less than 12% nor more than 16% of fixed carbon.

"Asphalt Cement L optional with asphalt cements H and K.

1. The asphalt cement shall be homogeneous, free from water and shall not foam when heated to 177° C (350° F).

2. It shall show a flash point of not less than 205° C (400° F).

3. Its specific gravity at a temperature of 25° C (77° F) shall be not less than 1.025 nor more than 1.055.

4. When tested with a standard No. 2 needle by means of a Dow penetrometer, or other pentrometer giving the same results as the Dow machine, it shall show penetrations within the following limits for the conditions stated, the penetrations being expressed in hundredths of a centimeter: 100 g load, 5 sec, at 25° C (77° F), from 60 to 70; 200 g load, 1 min, at 4° C (39° F), not less than 16.

5. Its melting point as determined by the cube method shall be not less than 55° C (131° F).

6. When 50 g of the material is maintained at a uniform temperature of 163° C (325° F) for 5 hr in an open cylindrical tin dish, 5½ cm (about 2¼ in) in diameter, with vertical sides measuring approximately 3½ cm (about 1½ in) in depth, the loss in weight shall not exceed 1% of the original weight of the sample.

The penetration of the residue, when tested as described in clause (4) with a standard No. 2 needle under a load of 100 g, for 5 sec at 25° C (77° F) shall be not less than one-half the penetration of the original material tested under the same conditions.

7. Its bitumen as determined by its solubility in chemically pure carbon disulphide at room temperature shall not be less than 99.5%.

8. It shall be soluble in chemically pure carbon tetrachloride at room temperature to the extent of not less than 99.5% of its bitumen as determined by clause (7).

9. It shall be soluble in 86° to 88° B paraffin naphtha, at least 85% distilling between 40° and 55° C (104° and 131° F), to the extent of not less than 67% nor more than 77% of its bitumen as determined by clause (7).

10. It shall yield not less than 13% nor more than 18% of fixed carbon.

Notes: Asphalt cements can be manufactured from Gilsonite and asphaltic oil to meet specifications A and H; from Texas asphaltic oils to meet specifications B and K; from California asphaltic oils to meet specification C; from Mexican asphaltic oils to meet specifications D and L; and from asphaltic materials from Bermudez to meet specification E. Tar cements can be manufactured from water-gas tars to meet

specification F; and from coal tars or a combination of a coal tar and a water-gas tar to meet specification G.

"**Delivery.** The asphalt cement or refined tar shall be delivered in suitable containers, far enough in advance of its use in the work to permit the necessary tests to be made. Each container shall be plainly labeled with the trade name of the asphalt cement or refined tar, name of manufacturer, gross weight and net weight. Each shipment and each carload shall be kept separate.

"**Bills of Lading.** The contractor shall furnish the engineer on or before the arrival of each shipment at or near the site of the work, bills of lading, or correct copies thereof which shall state the trade name of the asphalt cement or refined tar, and the name and address of the company manufacturing and supplying it.

"**Samples.** Samples will be taken by the engineer from each carload of asphalt cement or refined tar when delivered at the work, unless satisfactory arrangements can be made for sampling before shipment. Such samples shall be analyzed by the engineer to assure the delivery of an asphalt cement or refined tar of the specified quality and to determine, for purpose of payment, the quantity of bitumen.

"**Work Included.** Under this item the contractor shall furnish and deliver on the work at such points as directed an asphalt cement or an asphalt cement and a refined tar, which conform with the specifications heretofore mentioned. All asphalt cement or refined tar for any pavement of a given contract shall be furnished by one manufacturer and no change in type or grade of bituminous cement used in the bituminous concrete or the seal coat shall be allowed in any pavement of a given contract without written permission from the engineer.

"**Measurement and Payment.** The quantity of bitumen in the asphalt cement or refined tar, to be paid for under this item, shall be the number of tons, determined in accordance with the paragraph headed Samples, contained in the asphalt cement or refined tar placed in the pavement in accordance with the specifications and requirements, or used as directed for other purposes. The percentage of bitumen determined by an average of the analyses of the acceptable samples taken by the engineer during a given month, shall be used as the basis for payment for the asphalt cement or refined tar used during that month. Asphalt cement or refined tar that is wasted shall not be included in the measurement under this item. The price stipulated in this item shall include the cost of furnishing, hauling and delivering the asphalt cement or refined tar at points on the work where it is to be used, and all expenses incidental thereto."

U. S. O. P. R. 1918 Specifications for Bituminous Cements to be Used with a Mineral Aggregate Consisting of One Product of Broken Stone.

"**Bermudez Asphalt Cement, NA-3.** GENERAL. The fluxed native asphalt shall be homogeneous, free from water, and shall not foam when heated to 175° C (347° F):

"PHYSICAL AND CHEMICAL PROPERTIES. It shall meet the following requirements.

1. Specific gravity 25°/25°C (77°/77° F), 1.050 to 1.070;
2. Flash point, not less than 175° C (347° F);
3. Melting point, 40°C (104° F) to 50° C (122° F);
4. Penetration at 25° C (77° F), 100 g, 5 sec, 80 to 90;
5. Loss at 163° C (325° F), 5 hr, not more than 3.0%;
   Penetration of residue at 25° C (77°F) 100 g, 5 sec, not less than 40;
6. Total bitumen, soluble in carbon disulphide, not less than 95.0%;
   Inorganic matter insoluble, 1.5% to 3.0%."

"**Oil Asphalt Cement, OA-3.** GENERAL. The oil asphalt shall be homogeneous, free from water, and shall not foam when heated to 175° C (347° F).

"PHYSICAL AND CHEMICAL PROPERTIES. It shall meet the following requirements:

1. Specific gravity 25°/25° C (77°/77° F), not less than 1.010;
2. Flash point, not less than 175° C (347° F);
3. Melting point, 40° C (104° F) to 60° C (140° F);
4. Penetration at 25° C (77° F) 100 g 5 sec, 80 to 90;
5. Loss at 163° C (325° F), 5 hr. not more than 1.0%;
   Penetration of residue at 25° C (77° F) 100 g, 5 sec, not less than 50;
6. Total bitumen, soluble in carbon disulphide, not less than 99.5%;
   Organic matter insoluble, not more than 0.2%."

"NOTE: Material for any one contract shall not vary more than 0.020 in specific gravity nor more than 10° C (50° F) in melting point within the test limits above specified.

Methods of Testing. Tests of the physical and chemical properties of the asphalt cements shall be made in accordance with the following methods:

1. Specific gravity: Bul. U. S. Dept. Agr., 314, p. 5.
2. Flash point, open cup: Bul. U. S. Dept. Agr., 314, p. 17.
3. Melting point: Am. Soc. Test Mat. Tentative Standard D 36-16T, Proc. Am. Soc. Test Mat. 1916, p. 549.
4. Penetration: Am. Soc. Test Mat. Standard Test D 5-16.
5. Volatilization test: Bul. U. S. Dept. Agr., 314, p. 19, using 50 g sample.
6. Total bitumen: Bul. U. S. Dept. Agr., 314, p. 25.

"**Purpose and Use.** These specifications provide for material to be used in the construction of one-size stone bituminous concrete in the northern United States. NA-3 is intended to cover satisfactory grades of products prepared by fluxing Bermudez asphalt, and OA-3 satisfactory grades of oil asphalts prepared from Mexican, California, Texas and other petroleums.

"One-size stone bituminous concrete contemplates a mixture of the bituminous material with a crusher product passing a 1¼-in and retained upon a ½-in laboratory screen, or passing a 1-in and retained on a ¼-in laboratory screen. The bituminous material should be heated to a temperature of from 135° C (275° F) to 163° C (325° F), and the crushed stone to a temperature of from 66° C (150° F) to 121° C (250° F), before mixing. The mixture should contain from 5% to 7% bitumen. The hot mixture should be deposited in a uniform layer over a concrete or well-compacted broken stone or gravel foundation to such depth that it will yield a uniform layer 2 in in thickness after thoro rolling. A seal coat of the same bituminous material should be applied at the rate of 0.4 to 0.6 gal per yd and covered with a sufficient amount of stone chips to absorb the excess bitumen."

"**Water-Gas Tar Cement, TP-3.** GENERAL. The refined tar shall be homogeneous and free from water.

"PHYSICAL AND CHEMICAL PROPERTIES. It shall meet the following requirements:

1. Specific gravity 25°/25° C (77°/77° F), 1.150 to 1.200;
2. Float test at 50° C (122° F), 120 sec to 150 sec;
3. Total distillate by weight:
   To 170° C (338° F), not more than 1.0%
   To 270° C (518° F), not more than 10.0%
   To 300° C (572° F), not more than 20.0%
   Melting point of residue, not more than 65° C (149° F);
4. Total bitumen, soluble in carbon disulphide, 97% to 100%."

"**Gas-House and Coke-Oven Tar Cements, TP-4.** GENERAL. The refined tar shall be homogeneous and free from water.

"PHYSICAL AND CHEMICAL PROPERTIES. It shall meet the following requirements:

1. Specific gravity 25°/25° C (77°/77° F), 1.200 to 1.250;
2. Float test at 50° C (122° F), 120 sec to 150 sec;
3. Total distillate by weight:
   To 170° C (338° F), not more than 1.0%
   To 270° C (518° F), not more than 10.0%
   To 300° C (572° F), not more than 20.0%
   Melting point of residue, not more than 65° C (149° F);
4. Total bitumen, soluble in carbon disulphide, 80% to 97%.

"**Methods of Testing.** Tests of the physical and chemical properties of the refined tar shall be made in accordance with the following methods:

1. Specific gravity: Bul. U. S. Dept. Agr., 314, p. 5.
2. Float test: Bul. U. S. Dept. Agr., 314, p. 9.
3. Distillation tests: Am. Soc. Test Mat. Standard Test D 20-16.
   Melting point: Am. Soc. Test Mat. Tentative Standard D 36-16 T, Proc. Am. Soc. Test Mat., 1916, p. 549.
4. Total bitumen: Bul. U. S. Dept. Agr., 314, p. 25.

"**Purpose and Use.** These specifications provide for a material to be used in the construction of one-size stone bituminous concrete in the northern United States. TP-3 is intended to cover refined water-gas tar products, and TP-4 refined gas-house and coke-oven tar products.

"One-size stone bituminous concrete contemplates a mixture of the tar with a crusher product passing a 1¼-in screen and retained upon a ½-in laboratory screen, or passing

a 1-in and retained on a ¼-in laboratory screen. The tar should be heated to a temperature of from 107° C (225° F) to 135° C (275° F) and the crushed stone to a temperature of from 66° C (150° F) to 121° C (250° F) before mixing. The mixture should contain from 5% to 7% bitumen. The hot mixture should be deposited in a uniform layer over a concrete or well compacted broken stone or gravel foundation to such depth that it will yield a uniform layer 2 in in thickness after thoro rolling. A seal coat of the same tar or of hot asphalt (specification OA-6) should then be applied at the rate of 0.4 to 0.6 gal per sq yd and covered with a sufficient amount of stone chips to just absorb the excess bitumen."

Bituminous Cements for Southern United States. BERMUDEZ ASPHALT CEMENT specifications same as NA-3, except that the penetration limits at 25° C (77° F) are 70 and 80; the penetration of residue at 25° C (77° F), not less than 35; and the limits for inorganic matter insoluble, 2.0 and 3.5%.

OIL ASPHALT CEMENT specifications same as OA-3, except that the penetration limits at 25° C (77° F) are 70 and 80; and the penetration of residue at 25° C (77° F), not less than 45.

WATER-GAS TAR CEMENT specifications same as TP-3, and GAS-HOUSE AND COKE-OVEN TAR CEMENT specifications same as TP-4, except that the limits for the float test are 150 and 180 sec.

U. S. O. P. R. 1918 Specifications for Asphalt Cements to be Used with Modified Topeka Aggregate. For specifications covering the aggregate see Art. 8.

Bermudez Asphalt Cement, NA-5, for Northern United States. Same as specifications NA-3, except that the limits for melting point are 45° C (113° F) and 55° C (131° F); the penetration limits at 25° C (77° F), 60 and 70; the penetration of residue at 25° C (77° F), not less than 30; the total bitumen, not less than 94.5%; and the limits for inorganic matter insoluble, 2.0 and 3.5%.

Bermudez Asphalt Cement, NA-6, for Southern United States. Same as specifications NA-5, except that the penetration limits at 25° C (77° F) are 50 and 60; the penetration of residue at 25° C (77° F) not less than 25; the total bitumen, not less than 94%; and the limits for inorganic matter insoluble, 2.5 and 4.0%.

Oil Asphalt Cement, OA-5, for Northern United States. Same as specification OA-3, except that the penetration limits at 25° C (77° F) are 60 and 70; and the penetration of residue at 25° C (77° F), not less than 40.

Oil Asphalt Cement, OA-6, for Southern United States. Same as specification OA-5, except that the specific gravity must be not less than 1.020; the penetration limits at 25° C (77° F), 50 and 60; and the penetration of the residue at 25° C (77° F), not less than 30.

Purpose and Use. These specifications provide for asphalt cements to be used in the construction of graded fine aggregate bituminous concrete, and specifications OA-6 for an asphalt cement which may also be used as a seal coat on tar macadam or tar concrete pavements. NA-5 and NA-6 are intended to cover satisfactory grades of asphalt cements prepared by fluxing Bermudez asphalt, and OA-5 and OA-6 satisfactory grades of asphalt cements prepared from Mexican, California, Texas and other petroleums.

"The asphalt should be heated to a temperature of from 135° C (275° F) to 163° C (325° F), and the crushed stone to a temperature of from 121° C (250° F) to 149° C (300° F), before mixing. The mixture should contain from 7% to 11% bitumen. The mixture should be deposited in a uniform layer over a concrete or well compacted broken stone or gravel foundation to such a depth that it will yield a uniform layer 2 in in thickness after thoro rolling. A seal coat should not be necessary on this type of pavement."

Philadelphia, 1917 Specification for Warrenite Cement:

"General. The asphaltic cement shall be known as Warrenite Cement and shall be uniform in quality and shall contain no products obtained from coal, water-gas or oil-gas tar. It shall not be affected by water, and shall comply with the following tests:

"Penetration. The penetration at 25° C (77° F), measured by a No. 2 needle weighted with 100 g for 5 sec, shall be between 5 and 7 mm.

"Solubility. The cement shall be soluble in cold carbon disulphide, CS_2, to the

extent of at least 96%. The amount of cement which is soluble in cold carbon tetrachloride, CCl_4, shall be at least 98.5% of the amount of pure bitumen soluble in cold carbon disulphide. This test shall be made by the standard methods in subdued lights. The amount of the cement which is soluble in Pennsylvania naphtha at 88° B shall be between 72 and 84% of the amount of bitumen which is soluble in cold carbon disulphide.

"**Brittleness, Ductility and Evaporation.** The cement shall not be brittle at 13° C (55° F) when tested according to the following method: The test piece shall be a cylindrical rod ¼ in in diameter and 4 in in length and composed of cement of the same penetration as used in the mixture. The rod shall be supported on two grooved wheels 1 in diameter at bottom of groove, placed 1⅞ in apart, center to center. A pitman, consisting of a ¼-in sq brass rod and weighted to 5 lb, shall be so placed in the machine as to descend vertically directly over the center of test piece, and is clamped in this position with the lower end of the pitman, which is grooved to fit the ¼-in test piece, just touching the test piece. The test piece shall be brought to and maintained at the desired temperature for 5 min before testing. In order to maintain constant temperature while testing, the whole machine shall be submerged in water at the desired temperature. When the pitman is released by the clamp it will either break the test piece or bend it. If the former, the temperature of test piece and apparatus shall be raised 0.56° C (1° F) and test repeated until the actual brittle point is determined. Care must be observed to maintain test piece and apparatus 5 min at each temperature before testing. The cement, of a penetration as used in the mixture, shall show a ductility of at least 20 cm when tested according to the District of Columbia method. Twenty grams of cement, when placed in a flat-bottom dish 2½ in in diameter and heated for 5 hr at 163° C (325° F), shall not lose more than 2½% by weight and the penetration of the residue, when tested with a No. 2 needle weighted with 100 g for 5 sec, shall be not less than 50% of the original penetration of the cement.

"**Cementing Strength.** The cement, when tested at 15° C (60° F), according to the following method, shall show a cementing strength of at least 2500 g, this being the total weight in grams required to break a pat of asphaltic sand mixture consisting of the following: Asphaltic cement to be tested, 8.0%, sand passing a number 30 and being retained on a number 50-mesh sieve, 92.0%. The pat shall be mixed hot and compressed into a mold to take a pat 2½ in in length, 1 in in width and ½ in in thickness. The test shall be made by placing the pat horizontally across the top edges of two ⅛-in brass plates set on edge, so that the area of the pat between the supports shall be 1 sq in. The pat shall then be acted upon by a T shaped pitman bearing down upon the pat midway between the supports. The weight on the pitman shall be increased at a uniform rate from zero to a weight sufficient to break the pat, and the final weight shall be that given in the report."

For additional specifications for bituminous cements to be used with mineral aggregates of bituminous concretes of Classes A, B and C, see Art. 17.

CONSTRUCTION

11. Mixing Plants and Tools

To meet the demand for mixing plants with which various types of mineral aggregates can be economically heated and mixed with bituminous cements, several machines have been designed in the United States. Requirements which plants should fulfil vary to a considerable extent, due to the different kinds of aggregates and bituminous cements employed.

Tools. See Sect. 17, Art. 13.

Plants for Hand Mixing. A plant for hand mixing of unheated aggregates with hot bituminous cement consists of a mixing platform, three or four heating kettles, long-handled shovels, long-handled dippers, and small tools. Sheet-iron and wooden platforms have been used, but the latter, when consisting of two sections, is preferred, as it can be used more efficiently and is more easily moved. A two-section wooden mixing board should be made of 2-in plank. Each section should be 8 ft long and 8 ft wide.

The kettles should be of such shape and size as will enable them to be easily moved. No kettle, however, should be used which will not hold 150 gal of bituminous cement.

Cement-Concrete Mixers. Unheated broken stone has been mixed with tars (see Art. 12) or heavy asphaltic oils in the ordinary type of concrete mixer. Asphalt cements of low penetration at normal temperatures cannot be mixed with unheated aggregates in this type of plant, as it is generally impracticable to coat the unheated broken stone with the hot asphalt cement. This class of mixers should not be used for the construction of asphaltic concrete pavements unless the aggregate is heated in rotary driers.

Cement-Concrete Mixers with Heating Devices. There are several different types of this class of mixing plants in current use. In one type, the heat, in the form of hot air, is passed into the mixer by means of a large iron pipe, which runs from the fire-box to the outlet end of the mixer. A second type consists of a cylindrical mixer mounted on a four-wheeled truck; heat is obtained from a hot-air jacket entirely surrounding the cylinder except on the ends, and by means of a kerosene torch inserted within the drum. In a third type, hot air obtained by the combustion of oil in air is used to heat the mineral aggregate in the mixing chamber; after the aggregate is heated, the bituminous cement is added. A fourth method of utilizing concrete mixers is to use a rotary drier, as a part of the plant, for drying the aggregate.

Driers, Storage Bins, Weighing Devices, and Mixers. In a complete plant for the manufacture of bituminous concrete, the aggregate is carried by bucket-elevators to rotary driers, where it is dried and the dust exhausted; from the drier the aggregate is raised by elevators to storage bins or to screens from which the aggregate, in several sizes, falls into storage bins; when required the aggregate is drawn from the bins to a weighing device, and from there deposited into a mixer. Such plants are also equipped with bituminous cement heating tanks and weighing buckets.

Details of Plants and Methods of Operation. Certain essential features of plants for mixing different types of bituminous concretes are discussed in Arts. 12, 14 and 16. For comprehensive descriptions and methods of operation of several types of portable plants, especially designed for mixing bituminous concretes of Classes A, B, and C, see (63). Description of some plants and methods of operation are included in this Article, and in Arts. 12, 14, and 16. Plants, especially designed for the manufacture of sheet-asphalt binder and surfaces mixtures, are fully described in Sect. 17, Art. 13, and their operation and inspection explained in detail and discussed in Sect. 17, Arts. 14 and 16.

Specifications for Mixing Plant for Class B or C Aggregates, by Kirschbraun (48h). "The paving plant shall be of an approved type, properly adapted for producing the character of mixture hereinafter described. It shall consist of separate units for melting and preparing asphaltic cement, a drier for heating mineral aggregate, a screen and storage bin, having at least two compartments whereby the mineral aggregate may be separated by means of a 6 or 8-in screen into two sizes, that passing thru the screen being collected in one compartment, while the rejection is collected in another compartment. Plant shall further be equipped with the necessary devices for weighing separately the fine and coarse aggregate from each compartment of the storage bin. An asphalt cement bucket shall be provided with scales attached in order that the amount of asphaltic cement which is put into the mixture may be properly gauged. The mixing unit shall consist of a twin pug-mill mixer or its equivalent with blades so spaced as to produce a thoroly homogeneous mixture."

Type of Plant Required for Topeka Mixture, by Richardson (57e). "If the mineral

aggregate as it comes heated from the drums is collected in a single bin, segregation takes place. The particles of stone are not uniformly distributed in the bin, and they are still further separated in drawing a charge from the bin to the measuring box. The result is a lack of uniformity in the grading of the mineral aggregate in the mixture as it is sent to the street. This may be illustrated by data showing the composition of a surface mixture produced in this way. In a locality where a rather extended piece of construction was carried out, involving the analysis of 16 samples, the mixture varied as shown by the following figures:

Bitumen	7.7%		9.8%	
200-mesh	11.8%		11.7%	
80-mesh	6.5%		8.0%	
40-mesh	22.5%		39.0%	
10-mesh	22.0%		18.0%	
4-mesh	5.5%	30.0%	4.0%	13.5%
2-mesh	24.5%		9.5%	
	100.0%		100.0%	

"To avoid results such as are illustrated by the previous figures, a plant should be provided in which proper screens separate the hot mineral aggregate into coarser and finer portions which are collected in separate bins. Under such conditions the proportion of coarse to fine aggregate can be better regulated by weighing the two components separately. The grading of a surface mixture turned out at a plant providing such facilities is shown by the following figures:

Bitumen	8.2%		8.1%		8.9%		8.9%	
200-mesh	10.3%		7.9%		9.6%		9.6%	
80-mesh	9.0%		10.0%		8.0%		7.5%	
40-mesh	24.5%		23.0%		24.5%		23.0%	
10-mesh	20.0%		19.0%		20.5%		18.0%	
4-mesh	15.5%	28.0%	20.0%	32.0%	15.5%	28.5%	15.5%	33.0%
2-mesh	12.5%		12.0%		13.0%		17.5%	
	100.0%		100.0%		100.0%		100.0%."	

Use of Cement-Concrete Mixer with Heating Devices for Mixing Topeka Bituminous Concrete, by Drowne (17c). "During the summer of 1912, the writer supervised the construction of a Topeka pavement on the Service Test Road in Philadelphia, on which a portable mixing plant of small type was used. This mixer is known commercially as the Rapid Heated Mixer. Essentially, the machine consists of a four-wheeled truck; at one end of which is mounted a boiler and engine, and at the other a small cylindrical rotary mixer. Between the boiler and the mixer is a platform on which the loading is done. The mixing drum is surrounded with a hood, furnishing a heating space of about 3 in between the shell of the latter and the mixer. The heat for this hood is furnished by a coal fire directly under the mixer. Additional heat is obtained from a kerosene torch which may be inserted within the mixing drum. A vertical blade running spirally around the inside of the drum serves to lift the material from the bottom and carry it to the top of the mixer, as the latter revolves. The material then falls to the bottom, and the same operation is repeated. The discharge spout is fixed in the center of the drum at the rear of the machine. The capacity of the mixer is 12 cu ft or a batch of about 1300 lb, including the bituminous cement.

"The various materials were taken from the stock piles in wheelbarrows to the loading platform and dumped into the mixer. The kerosene torch was then inserted within the drum, and, as the mixer revolved, the material cascaded thru the flame of the torch and was heated to a temperature of about 100° C (212° F). When this temperature was reached, the torch was withdrawn, and the asphalt cement, which was heated to about 177° C (350° F), was poured in. A cover was then placed over the opening in the loading end of the mixer. The batch was allowed to mix with the asphalt for from 1 to 2 min, at the end of which time a perfect mix was secured having a temperature of 121° C (250° F).

"The output of the machine varied, depending on the dryness of the mineral aggregate. On an average, from 4 to 5 batches were mixed per hr. When the materials

were warmed before being put in the mixer, 6 batches per hr were mixed for 1 or 2 hr, or as long as the warm material lasted. One batch of material would lay about 5 sq yd of pavement, 2 in thick when rolled. The pavement was constructed on a macadam foundation, and there was some loss, due to the material being compressed into the voids of the surface. If laid on a concrete foundation, one batch would probably have made a somewhat greater yardage. The manufacturers of this machine claim an output of 250 sq yd per 10-hr day per machine. It is generally recommended that these machines be used in pairs. It takes from 6 to 12 min to bring the material up to the proper temperature before adding the asphalt cement. If only one machine is used, and 4 or 5 batches per hr are mixed, the time required for each batch is from 12 to 15 min, therefore, considerable time is wasted by the men working around the machine. If the machines are used in pairs, the men can be kept busy practically all the time. It is the only economical way to use machines of this type. The output of two of them in a 9-hr day would be about 360 sq yd.

"If the cost of labor is $2 per day, 7 laborers being required, and 1 engineer at $3.50 per day, the labor cost of the operation would be about 4.8 cents per sq yd on a basis of 360 sq yd per day. The cost of coal, kerosene for the torch, depreciation of the machine, and supervision, would add probably about 4.5 cents, making a total cost of 9.3 cents per sq yd."

Bitulithic Plant and Its Operation by Perkins (54). "The operation of a semi-portable Bitulithic plant is as follows: The raw materials, namely, crushed stone, screenings, and sand, are fed from the storage piles at the rear of the plant into the cold stone elevators, are heated in the driers, then elevated to the rotary screen, which is enclosed in a screen house to prevent the dust scattering over the neighborhood. This screen consists of the several sections which are required to separate the mineral aggregate into the various sizes. The hot stone passing each of these screen sections drops into its compartment in a sectional bin and is thus kept separate from other sizes. The boxman weighs out the amount of each size required into a weigh-box supported on platform scales with a multiple beam which enables him to weigh each size separately and accurately. It is impossible to formulate a standard screen test or rule as to just what proportion of each size particle of mineral aggregate is required to produce the maximum density or minimum of voids, because the stone from different quarries crush into different shapes. By following the best practice under the Warren patents as described, the resulting combination of varying sizes of mineral aggregate will contain approximately 12% of voids to be filled with bitumen. While the weighing is taking place the mixer-man has filled the bitumen bucket with the required weight of Bitulithic cement by dipping from the melting tanks, the weight of bitumen being accurately measured by scales on the bucket carrier. The bitumen and mineral aggregate are then emptied into the mixer and thoroly mixed until all particles are completely coated and the mass has been transformed into a uniform bituminous concrete, when the slide under the mixer is opened and the batch dropped into the wagon waiting under the platform.

"A standard one-car railroad Bitulithic paving plant embodies all of the features of the semi-portable type and in addition has the advantage of being built on a single steel car and therefore can be more quickly erected ready to run after arrival at the destination. In addition to this, the mixing platform overhangs the side of the car, so that if the ground surrounding the plant will allow it, the wagons can be driven under the mixer from the rear, thus avoiding the delays due to backing under. There are three large kettles, two for melting and one, next to the mixer, for use as a dipping kettle, this kettle being covered and provided with an air-tight manhole cover so that the Bithulithic cement may be forced with compressed air from it to the bitumen weigh-bucket. The dial of the scales has two movable stops which are placed at the proper points for the weight of the bucket empty and full, which enables the plant foreman to tell at a glance whether the mixer-man is weighing accurately or not. These scales and the stone scales are tested daily with three standard test weights in order to detect as soon as possible any lack of adjustment."

Warrenite Plant and Its Operation by Perkins (54). "While the mixture produced by these plants is much like Bitulithic, the methods by which it is obtained are radically different from those in use with the Bitulithic plants. The crushed stone, screenings and sand are placed in separate piles, and the required proportion of each size as previously determined by laboratory test is measured into the drying section of the

plant and there remains until dried. One full batch of mineral aggregate measured in this manner is fed into the elevator and raised to the hopper. After the entire batch is in the hopper, the gate in the chute allows it to descend into the heater drum, which is heated by an oil flame thru the combustion chamber. While the batch is being heated it is slowly forced forward by spirals inside the drum towards the mixing chamber. When it is hot enough a gate or chute suspended between the heating and mixing chambers of the drum is tilted and conveys the entire batch into the mixing chamber, where it is thoroly mixed with Warrenite cement poured in thru a funnel above the platform. The bitumen is weighed accurately in a bucket on spring scales, the same as in a Bitulithic plant. When the batch is mixed it is delivered into the wagon by another tilting chute at the forward end of the mixing chamber. While one batch is going thru this process, other batches have been successively started, so that at any one moment there are, one batch in the mixer, one in the heater, one in the hopper, and one being measured in the wheelbarrows; yet on account of the design of the plant each batch is kept entirely separate and distinct from every other and for that reason it is possible to control the mixture and keep the proportions of the various sized particles of the mineral aggregate constant and uniform."

12. Construction of Class A Pavements

The methods of mixing and laying Class A bituminous concretes vary dependent upon the mixing plant employed, the characteristics of the aggregate and bituminous cement used, such local conditions as traffic, availability of skilled labor, etc, and the type of pavement constructed.

Hand Mixing. Bituminous concrete of Class A may be manufactured by hand mixing, using unheated or heated aggregate provided that a bituminous cement is used, which, when heated to a proper temperature, may be easily incorporated with the aggregate so that each particle is thoroly coated. Practice has demonstrated that hand mixing of unheated aggregates and coal tar, water-gas, or cut-back asphalt cement is practicable. If heated aggregates are used, the range of usable bituminous cements is, of course, increased. In connection with hand mixing, however, usually only crude methods of heating have been employed, such as the use of hot plates or pipes upon which the aggregate is placed and agitated from time to time by hand methods. These crude methods of heating should not be employed as the general result is uneven heating of the aggregate and, in many cases, burning of the batches of bituminous concrete due to overheating of the aggregate. Generally speaking, crude methods and appliances are used with hand mixing, and it should be realized that this method of manufacture is a makeshift and should only be used under special conditions, as on short sections or where it is impracticable to use a mixing plant. With the multiplicity of plants in use and their general availability, few are the cases where hand mixing is justifiable.

The ordinary method of using the hand mixing method for the construction of pavements on highways outside of urban districts is as follows: The aggregate, which should be clean and dry, is deposited upon mixing boards placed on the foundation course a few feet in front of the bituminous concrete in place. In using a two-section mixing platform, the aggregate should be deposited at the end of the platform farthest from the bituminous concrete in place. The bituminous cement, after having been heated to the proper temperature in portable kettles, is distributed over the pile of aggregate by means of long-handled dippers. Mixing with long-handled shovels is then begun, the coated aggregate being turned over towards the end of the platform nearest the bituminous concrete in place. During the process of mixing, more bituminous cement is added until the total amount per 1 cu yd of loose aggregate is from 15 to 21 gal, the proper amount being

dependent upon the composition and kind of aggregate, and grade of bituminous cement. After the aggregate is thoroly coated, it is deposited in place by shovels. The bituminous concrete should not be cast onto the foundation, but each shovelful should be carried and deposited next to bituminous concrete in place. Before the next load of aggregate is dumped, the section of the mixing platform nearest the bituminous concrete should be transferred to a position adjoining but just ahead of the other section. For further discussion of hand mixing methods, see (53a) and (61b).

Machine Mixing. The details of the operation of mixing bituminous concretes will depend, to a certain extent, upon the type of machine employed.

CEMENT-CONCRETE MIXERS have been used with both unheated and heated aggregate. In the former case, the remarks relative to adaptability of the hand mixing method apply with equal force. If independent rotary driers constitute part of the plant equipment, excellent results may be secured with any of the bituminous cements used with Class A aggregates. Generally, the operation of a plant made up of independent units will not be as efficient or economical as when portable combined plants are used. Very good results have been obtained, with careful supervision, by using cement-concrete mixers with heating attachments consisting of hot air blasts or torches. It should not be expected that as uniformly heated aggregate or as high temperatures can be obtained as with rotary driers.

Except in the case of the use of an independent rotary drier unit, the aggregate in general is measured in wheelbarrows. The bituminous cement is measured by volume or weight, dependent upon the plant accessories. After the aggregate has been heated to the desired temperature, the bituminous cement is added to the aggregate in the mixing chamber. The mixture is agitated until each particle is thoroly coated. The bituminous concrete is discharged by the mixer into wheelbarrows, wagons, or trucks, transported to the site of the pavement under construction, and deposited on dumping boards.

Use of Cement-Concrete Mixers in Rhode Island by Poore (17c). "Refined coal tar was used as a binder, this material being shipped in tank cars to the nearest railway station, where it was steam-heated and barreled by the contractor. During the height of the season, 18 mechanical mixers were in operation, laying daily a total of 3000 ft of 14-ft road surface, 2 in thick. The type of mixer generally used was one manufactured by the Municipal Engineering and Contracting Co. It is similar to the ½-yd cube batch cement-concrete mixer, and has an oil torch heating device for use when bituminous concrete is mixed. The machine is mounted on four wheels for transportation. It consists of a revolving iron box, mounted on its diagonal axis, and driven with direct gearing by the steam engine mounted on the same frame. The mixed material is discharged by tipping the cube, and the mixing chamber is loaded with a sliding skip operated by a small cable hoist. An air compressor for supplying the oil torch is belted to the engine. Common fuel oil under air pressure forms a blast in the center of the mixing chamber sufficient to dry the mineral aggregate and expedite the work during cold weather. As the specification called for a cold mix, the blast was not necessary thruout the day's work.

"The plants were operated in two ways; either as a portable plant moving along the road each day, or as a stationary unit at the stone crusher. The first method was followed where the work consisted of scarifying the old macadam and adding a new 2-in bituminous concrete surface. Set-ups were made at the intervals covered in a day, usually about 200 ft. A 12 by 12-ft dumping board was used under the loading skip, on which to dump the broken stone hauled from the railroad siding or stone crusher. The mixer was placed on planks in the center of the road, being hauled ahead by the steam roller at the end of the day. Two 150-gal portable kettles provided sufficient hot bituminous material. The proper quantity for a batch was measured out by hand and carried in buckets from the side of the road to the loading chute. Six iron barrows, well oiled to prevent the coated stone from sticking, were used in

carrying the hot mixture to the road, where it was raked out to the required depth.

"When the mixer was used as a permanent unit at the stone-crushing plant, the mixer platform was built at the same elevation as the bottom of the stone bins, and from the latter the stone could be discharged directly to the loading skip. To allow the uncoated stone for the foundation course to fall by gravity into wagons, it was necessary to leave an intervening space of 7 or 8 ft between the stone bins and the mixer platform. Many of the mixers ran three ½-cu yd batches in from 10 to 15 min. A 1½-cu yd bottom-dump wagon was placed to receive these three batches, and then hauled to the road, a 2-mile haul often being economical. There was no chilling of the mixture. A larger kettle was used at the stationary plants than on the resurfacing work. The buckets of hot bituminous material were handed from the ground by the kettleman to the man on the raised mixer platform, and he emptied them into the mixer chute. One engineer, one helper, one loading man, and one kettleman were required for the mixer when in operation. Practically 600 sq yd of 2-in surface were turned out per day at each plant."

Stationary, Semi-Portable and Portable Self-Contained Mixing Plants of many types have been successfully employed in the manufacture of Class A bituminous concretes. Naturally the most economical and efficient work has been accomplished by plants especially adapted for mixing Class A aggregates. Generally, on highway work outside of urban districts, the portable plant proves most satisfactory. Dependent upon the plant accessories, the aggregate is measured by volume or weight before being dried or by weight after drying, the latter being preferable. The aggregate is usually dumped into bucket elevators, which discharge into rotary driers. In the best types of plants, the heated aggregate is then raised by bucket elevators and discharged into a small storage bin. As desired, the heated aggregate is drawn from the storage bin and allowed to fall directly into the pug mill mixer or, preferably, first into a weighing box. The bituminous cement is weighed in scales on the mixing platform and then dumped into the mixer. After thoro mixing, the bituminous concrete is usually discharged into a wagon or truck, which the plant arrangement permits to be placed directly beneath the mixer.

Comparison of Mixing Methods by Warren (71a). "The mixing methods are of two general classes as to hardness of bitumen, known as cold process and hot process, and two classes as to method of mixing, known as hand mixing and machine mixing, which will be treated in the order named. The cold process means the use of a mixture of stone and bitumen of such a character that the ingredients can be mixed and laid without artificial heat, that is, at the temperature of the air. This necessitates the use of bitumen of a character which is liquid when cold and is necessarily deficient in cementing strength unless the bitumen is made liquid by the use of a volatile temporary liquefier which will evaporate soon after the roadway surface is laid. The cold process is also necessarily subject to the weakness that the moisture has not been evaporated from the aggregate before adding the bitumen, which seems to be bad practice to say the least. In the writer's judgment, other things being equal, the hot process gives the best results; but it is necessarily more expensive both on account of the more or less expensive plant required to heat and mix the ingredients, but also the greater amount of labor required to heat and roll the much tougher, denser and harder surface mixture. The hot process has the great advantage of providing a surface which is set hard as soon as compressed and chilled to the temperature of the air.

"Hand Mixtures have the following advantages over machine mixtures:

1. Comparatively little expense of plant installation on account of which it is applicable for use on roadways of less area than practicable by machine methods.

2. No cost of fuel and consequent saving.

3. Some writers say machine mixing labor is less than hand mixing, but, taking all items of cost including plant installation and delivery of materials to and from the mixing plant, and labor for mixing and laying, into consideration, the writer believes as a rule the reverse is the real condition.

"The disadvantages of the hand mixing processes are:

1. Manifestly less thoro mixing and less accurate proportioning and uniform distribution of ingredients and consequently greater variableness of results than with a properly constructed mixing and heating plant.

2. Because of greater ease in hand mixing, a marked tendency toward use of softer bitumen.

3. Impracticability of getting a thoro mixture without more power than can be executed by hand mixing if the combination of ingredients are as dense as they should be to produce the best results.

"MACHINE MIXING methods may be sub-divided into several classes as follows:

1. Mixing without accurately proportioning or heating ingredients for which ordinary concrete mixers, either of the continuous or batch types, will answer. This method has the advantage of least expense in plant and labor which, in the writer's judgment, is very much more than counterbalanced by the disadvantages of using bitumen of a grade so soft as to be liquid at normal temperature and of less accuracy and uniformity of results.

2. Mixing by heating without accurately proportioning the ingredients which, in the writer's judgment, is better than the last named method but still inherently defective.

3. Using a well planned mixing and heating machine specially constructed for the purpose, which will produce the following essentials to a maximum degree of success:

a. Uniformity and accuracy of proportioning of ingredients both as to varying sizes of mineral aggregate and amount of bitumen.

b. Sufficient heat in the ingredients when mixed and laid in the work to evaporate moisture and permit the use of bitumen hard enough to furnish a true binder.

c. When compressed in the work a solid, dense, voidless, dry, bituminous concrete wearing surface which will to the greatest possible extent prevent penetration of moisture, the enemy of all road surfaces, and withstand the troublesome automobile and other traffic without shifting or presenting undesirably soft surfaces."

Details of Heating Aggregates, Bituminous Cements and Bituminous Concretes. See Am. Soc. C. E. Spec. Com. recommendations, in this Article, and Art. 8 for requirements covering heating of different aggregates and bituminous cements, and temperatures at which bituminous concretes should be laid.

Hauling Bituminous Mixtures by Mullen (49c). "Whether wagons or auto trucks will prove most economical is always a local problem. The auto trucks are good for long hauls with steep grades, but there is frequently greater economy in the wagon for short hauls with flat grades. Provisions should be made for the rapid loading and unloading of either, but especially the automobiles. The author remembers figuring on one job that cost 1 cent a minute to have a horse and wagon of 3 tons capacity stand for its load, and 5 cents per minute for a 5-ton auto truck. After that, a loading hopper was built.

"Canvas covers on the trucks are very good at all times, and especially in chilly weather when the crust of the mixture would otherwise become too stiff for proper raking. They should be so arranged that there is a 3 or 4-in air space between the cover and the load, however, as this not only saves the cover but also provides much better protection for the hot mixture.

"One cent per inch yard mile is a good formula to remember when considering the cost of hauling asphalt paving mixtures. That is, it cost about 1 cent to haul enough mixture to lay 1 sq yd of asphalt pavement 1 in thick and weighing about 100 lb on a street 1 mile from the mixing plant. Multiply 1 cent by the thickness in inches of the pavement, and that by the number of miles between the plant and the job. This is a rough and ready rule that should not be used for a bidding estimate, but it will help in quickly considering the comparative advantages of various available plant sites. It was the basis of a large asphalt hauling contract in New York City, at a time when team hire was $6 a day."

Laying. In cases where neither curbs, gutters nor edgings are used, thoroly compacted shoulders are constructed. To serve as definite boundaries and to prevent the bituminous concrete from being forced out over the

shoulders during rolling, 2-in planks may be placed on the shoulders at the edges of the roadway and allowed to remain until after the seal coat is applied.

After the bituminous concrete has been deposited on the foundation course, it should be uniformly spread by raking to a depth such that when compacted the wearing course will have the desired thickness, which is usually 2 in. For stiff bituminous concrete mixtures, heated shovels should be used for depositing the mix on the foundation course and hot rakes for spreading the bituminous concrete. Care should be taken to see that shovels and rakes are not overheated, as otherwise the mix may be burnt. Usually the back of the rakes should be used to spread the mix uniformly. If the tines are used for this purpose, the larger stones of the mix may be segregated in the surface of the wearing course.

After being uniformly distributed, the bituminous concrete is rolled while it is still warm and pliable. The rolling should begin at the edges and work towards the center. Rolling should continue, without interruption, until all roller marks disappear and the surface shows no further compressibility. Any places which the roller cannot effectively compress should be compacted with hot iron tampers. Excellent results can be secured by the use of tandem rollers, weighing between 10 and 12 tons and having a compression under the rear roller of from 250 to 350 lb per lin in of roll. Equally good results have been obtained by using a 5 to 8-ton tandem roller to shape up the wearing course, and a 12-ton three-wheeled roller for the thoro compaction of the bituminous concrete. In order to prevent ashes from dropping onto the bituminous concrete, each roller should be provided with an ash pan.

The surface of the compacted wearing course should be tested for irregularities and depressions. A 4-ft straight edge may be satisfactorily used for this purpose. When laid longitudinally on any part of the surface, or diagonally or transversely on each half of the roadway, in case a two-plane section is used, there should be no depressions over ⅜ in in depth. Should depressions or other irregularities be found which require correction, the tines of a rake should be used to loosen up the bituminous concrete if the mix is of such composition that it can be used to fill the depressions. If, however, the maximum sized particles are 1 to 1¼-in, the areas of the wearing course, where the depressions occur, should be removed and freshly mixed bituminous concrete used in making the repairs.

During the placing and compaction of the bituminous concrete and until after the completion of the seal coat, shoulders and adjacent driveways should be kept watered or oiled to prevent dust from accumulating on the surface of the bituminous concrete. Even a thin layer of dust on the surface of the wearing course materially decreases the strength of the bond between the seal coat and the bituminous concrete.

Seal Coat. After the wearing course has been rolled sufficiently so that the wheels of the roller do not make any creases, a coat of bituminous cement is applied to the surface. The seal coat should not be applied unless the surface is clean and absolutely dry. In many cases the bituminous concrete will have to be thoroly swept before the application of the seal coat. From ½ to 1 gal per sq yd of bituminous cement should be used, the requisite amount varying directly with the openness of the compacted bituminous concrete surface and the kind of bituminous cement used.

The best method of constructing a uniformly distributed seal coat is to use a hand-drawn gravity distributor or a hand-drawn pressure distributor;

for descriptions of which, see Sect. 14, Art. 6. If the gravity distributor is used, it should be followed by a man pushing a rubber or leather squeegee. The squeegee should have a width greater by from 4 to 6 in than the width of the sheet of bituminous cement as it falls from the distributor. By being kept from 2 to 4 in back of the sheet of bituminous cement, a very even distribution may be easily obtained. It is not economically practicable to use large distributors of the types employed in the construction of bituminous surfaces as it is not advisable to leave long sections of bituminous concrete exposed, due to the probability of the interstices becoming filled with dirt and the surface covered with a thick film of dust. The manner of applying the seal coat also may be as follows: The heated bituminous cement is placed in an iron-bodied wheelbarrow, the barrow being kept practically full of the hot cement while the same is being used. The bituminous cement is applied to the bituminous concrete surface from the wheelbarrow by means of brooms in the amount specified. Altho very fair results have been obtained by this method, it is not recommended, as the results secured with distributors are superior, especially from the standpoint of uniformity of distribution of the bituminous cement.

As soon after the application of the bituminous cement as possible, a thin layer of dry, clean chips should be uniformly spread over the coat of bituminous cement, the total amount of chips being preferably distributed in two applications. A safe rule to follow is not to allow the application of the chips to lag more than 20 ft behind the placing of the bituminous cement. In case the men distributing chips are close upon the application of bituminous cement, care must be taken to prevent the chips from being applied upon the wearing course of bituminous concrete. The chips should be rolled at least twice in order to force them into the interstices of the surface and secure the maximum bond with the bituminous cement.

Weather Conditions. It is, of course, impracticable to lay bituminous concrete during damp or rainy weather as the foundation must be dry before the bituminous concrete is deposited thereon and the wearing course surface must be dry before the application of the seal coat of bituminous cement. It is not advisable to lay bituminous concrete when the air temperature in the shade is below 10° C (50° F), due primarily to the difficulty in securing a thoroly compacted wearing course. After rains and during damp weather, a portable cascading or rotary drier will be found very useful for drying piles of wet chips. It is also advisable to have at hand several waterproof covers for use in covering piles of chips, the section of bituminous concrete upon which the seal coat has not been applied, and a short section of the foundation in advance of the bituminous concrete in place. The use of covers, in the manner indicated, will materially reduce delays caused by wet weather.

Conclusions, Spec. Com. Mat. Road Cons., Am. Soc. C. E. (17e). "HEATING AGGREGATES AND BITUMINOUS CEMENTS. Altho satisfactory pavements have been constructed using unheated mineral aggregates and suitable bituminous cements, service tests demonstrate that the best results are secured by using for the mineral aggregate broken stone which is heated until thoroly dry to between 66° C (150° F) and 121° C (250° F). If revolving driers in which the flame is permitted to come in contact with the aggregate are used, great care should be taken to insure uniformity of heating and so avoid the danger of burning the aggregate. In order to obtain a fluidity of the bituminous material which will be sufficient to ensure a proper coating of the mineral particles in cases where a heated aggregate is used, and also to prevent injury to the bituminous material, the asphalt cements should be heated to a temperature between 135° C (275° F) and 177° C (350° F), and refined tars to a temperature between 93° C (200° F) and 135° C (275° F).

"Mixing. The quantity of bituminous cement to be used in the mix will depend on the kind of broken stone or gravel and bituminous cement, the character of the aggregate, the climatic conditions, etc. For the aggregate heretofore mentioned (see Art. 5), the bituminous concrete mixture should contain between 5 and 8% by weight of bitumen. The bituminous concrete should be mixed in mixers designed and operated so as to produce and discharge a thoroly coated and uniform mixture of non-segregated aggregate and bituminous cement. Except on small contracts and for repair work, mixers which provide for the heating of the aggregate by the use of a flame in the mixing chamber should not be used, on account of the danger of burning the aggregate or the bituminous cement.

"Laying. To ensure ease of manipulation and the proper compaction of the bituminous concrete, the mixture as delivered on the roadway should have a temperature of not less than 66° C (150° F). Experience has demonstrated that a thickness, after rolling, of 2 in of bituminous concrete is economical and efficacious. In order to secure an even surface and adequate compaction by a thoro interlocking of the particles of the aggregate, a tandem roller weighing between 10 and 12 tons should be used.

"Seal Coat. A seal coat should always be used on this type of bituminous concrete, as maintenance charges and annual cost will be reduced materially thereby. The seal coat should consist of from ½ to 1 gal per sq yd of bituminous cement, uniformly distributed, preferably by the use of a hand-drawn distributor followed by a squeegee. The bituminous cement should be covered with an application of dry stone chips, which should be rolled.

"Seasonal Limitations. Bituminous concrete of this type should not be mixed or laid when the air temperature in the shade is lower than 10° C (50° F), as otherwise it will be difficult, under average conditions, to secure an even and well compacted wearing course."

Details of Construction of the Ashokan, N. Y., Bituminous Concrete Pavement on part of the 32-mile contract for a highway around the Ashokan Reservoir of the Board of Water Supply of New York City are described as follows (20):

"The bituminous concrete was mixed so that the resulting mixture contained, by weight, 6.25% of asphaltic cement, the stone ranging in size from ¼ to 1¼ in. The temperature of the stone, after drying and heating, was fixed at a maximum of 107° C (225° F), and the asphalt ranged from 135° to 149° C (275° to 300° F), as it was found that these temperatures reduced the draining from the wagons to a minimum.

"The resulting mixture was hauled to the place of laying in bottom dump wagons. The mixture, temperature not less than 66° C (150° F), was dumped onto platforms consisting of planks placed loosely side by side, a few feet in advance of laying. From here it was shoveled into place and spread with rakes to the requisite thickness for rolling with an 8-ton tandem roller to a compacted thickness of 2 in. It was found that the compression due to rolling was generally ⅝ to ¾ in. The amount of asphaltic cement, including seal coat, averaged 19.2 lb or 2.3 gal per sq yd of road surfaced. A single plant, Cummer, laid as much as 1500 sq yd of 2 in bituminous surfacing in one day, but 700 to 800 sq yd, omitting delays, was about the average.

"After rolling, a seal coat, not to exceed 1 gal per sq yd, was spread and covered with stone chips. The dry stone chips were spread in two operations. The first spreading was very light and the rolling resulted in forcing the chips into the seal coat between the interstices of the coated stones of the wearing surface. After a thoro rolling a more liberal coating of stone chips was spread and rolled. The surface was then ready for traffic.

"For purposes of operating, the roads to be surfaced with bituminous pavement under this contract were divided into four groups. On roads of Group A, the plant the contractor had in effective operation consisted of from one to four, mostly three, stone outfits and one asphalt outfit. On these roads (during 1914) 51 700 lin ft of 6-in foundation courses, 14 ft wide, were laid, and 88 000 sq yd of 2-in bituminous surface and seal coat. Effective progress was made on 155 days out of a total of 170 days for foundation courses, and 98 days for bituminous surfacing out of a total of 160 days, so that the total daily average rate for foundation courses was 304 lin ft, and 550 sq yd for bituminous surface."

Construction of Class A Pavements Composed of Two or More Layers of Bituminous Concrete. The use of this type of bituminous concrete

pavement since 1900 has been mostly confined to Great Britain. The aggregates have been mainly granite and slag, the use of the latter largely predominating. The excellent tar slag concrete pavements known as Tarmac, which have been laid in England since 1903, are of this type. Altho laid by various municipalities, the largest yardage of this type has been constructed by Tarmac, Ltd. One of the Tarmac plants is located at Wolverhampton, adjacent to the works of a company producing large quantities of blast-furnace slag. The large molds of slag are transported by small cars from the iron works on a narrow gauge track and dumped near the Tarmac plant. These large blocks, while still warm, are broken by sledge-hammers to sizes suitable for the crusher. After it is crushed and screened into sizes varying from ¼ to 2½ in, it is mixed with a tar compound. Since the slag is warm, even after it has been crushed, no heating, preliminary to mixing, is necessary.

Altho in some cases two courses of tar slag concrete are used, usually more than two layers of tar-coated slag are employed. The principal features of the construction of three-layer tar slag concrete pavements are covered by the following description of a Tarmac pavement laid at Brighton-on-Sea, England. On a well-compacted gravel foundation there was spread a scattering of tar-coated slag chips; the bottom layer was composed of 2½ in of compacted 1¼ to 2½-in tar-coated slag; the second course consisted of 2 in of compacted ½ to 1½-in tar-coated slag; the third course was composed of a thin layer of ⅛ to ⅜-in tar-coated slag chips, which layer was thoroly rolled; the pavement was finished by rolling a top dressing of uncoated fine slag screenings.

Directions for Laying Tarmac by E. Purnell Hooley, County Engineer of Nottingham, Eng. "Before the applying of any Tarmac, the surface of the road that will be left in the center must be carefully swept, and all dirt, dust or loose material removed. The ⅝-in gauge material will always arrive first, and should this not happen, notice must at once be given to the County Surveyor. The ⅝-in must then be lightly spread as a fine bottom layer to fill up any unevenness, to prevent water rising from the under side, and to minimize crushing. The ⅝-in should only be spread about a yard in width at a time, so as to prevent its being trodden upon by the workmen when spreading. On this ⅝-in must immediately be laid a layer of 2¼-in gauge Tarmac, each piece being packed as close to its neighbor as possible. Generally the passage over of the roller about four times each way is sufficient to consolidate this first 2¼-in layer, and the roller must at all times roll the sides towards the center. When the surface is thus rolled, a small dressing of ⅝-in gauge Tarmac must be carefully swept with a dapping motion of the brush into every interstice, and not again rolled until an application of 1½-in Tarmac shall have been applied. The roller then shall pass over this 1½-in gauge material about three times each way, rolling from the sides to the center. A sufficient quantity of ⅝-in material shall again be applied to fill up the interstices, and the roller passed over to place this filling in position. On the completion of the whole, a dressing of fine dry slag dust shall be swept over the surface. After the first rain has soaked the slag dust, the workmen shall immediately sweep the whole road from the center to the sides to remove any surplus dust from the Tarmac, and use as much as possible of this surplus dust on the dry sides, if necessary, or remove it entirely from the surface to the nearest depot. Each 7 sq yd of finished Tarmac road should contain approximately 1 ton. Each 100 ton of material, if laid by this system, should consist of: 3 ton of ⅜-in dry slag; 12 ton of ⅝-in Tarmac; 40 ton of 1½-in Tarmac; 45 ton of 2¼-in Tarmac."

13. Specifications for Class A Pavements

Mineral Aggregate Composed of One Product of a Stone Crushing and Screening Plant. Am. Soc. Mun. Imp. 1917 Specifications. For specifications for the mineral aggregate, see Art. 8. For specifications for the bituminous cements, see Art. 10.

"**General Description.** The bituminous concrete wearing course shall consist of a compact mixture of broken stone and asphalt cement or refined tar laid to conform to the required grades and cross-sections, covered with a seal coat of asphalt cement and broken stone chips, and constructed as hereinafter specified.

"**Heating Mineral Aggregate.** Before entering the mixer, the broken stone for the mineral aggregate shall be heated until thoroly dry to between 66° C (150° F) and 121° C (250° F), as directed, in revolving driers in which no flame shall be permitted to come in contact with the broken stone and in which the broken stone shall be continuously agitated during the heating.

"**Heating Bituminous Cement.** The asphalt cement or refined tar shall be heated in kettles so designed as to admit of even heating of the entire mass, with an efficient and positive control of the heat at all times. Asphalt cement shall be heated as directed to a temperature between 135° C (275° F) and 177° C (350° F). All asphalt cement heated beyond 177° C (350° F), either before or during mixing with the broken stone, shall be rejected. Refined tar shall be heated as directed to a temperature between 93° C (200° F) and 135° C (275° F). All tar heated beyond 135° C (275° F), either before or during mixing with broken stone, shall be rejected. No tar shall be heated in kettles containing any asphalt cement and in like manner no asphalt cement shall be heated in kettles containing any tar. Before changing from one type of material to the other, kettles shall be scrupulously cleaned in order to avoid mixtures of the two. Any such mixtures resulting from this cause shall be rejected.

"**Thermometers Furnished by Contractor.** The contractor shall provide a sufficient number of accurate, efficient, stationary thermometers for determining the temperature of the asphalt cement or refined tar in kettles.

"**Mixing.** When thoroly heated to the temperature directed, the asphalt cement or refined tar and the broken stone for the bituminous concrete shall be mixed so that the resulting mixture shall contain between 5 and 8% by weight of bitumen, as directed, depending primarily upon the kind of bituminous cement and mineral aggregate which are used. A mixer shall be used, having revolving blades, and so designed and operated as to produce and discharge a thoroly coated and uniform mixture of non-segregated broken stone and bituminous cement. When discharged, mixtures of asphalt cement and broken stone shall have a temperature not more than 149° C (300° F) and not less than 93° C (200° F) as directed. When discharged, mixtures of refined tar and broken stone shall have a temperature not more than 121° C (250° F) and not less than 66° C (150° F).

"**Surface of Foundation.** Before laying the bituminous concrete, the surface of the cement-concrete foundation shall be dry and thoroly cleaned. If any defective areas exist in the cement-concrete foundation, they shall be repaired as directed at least 10 days in advance of laying the bituminous concrete. In cases where cement-concrete edging is not used, compacted shoulders, forming a continuation of the surface of the foundation, shall be constructed. A 2-in plank shall be laid on each shoulder at the edge of the foundation. These planks shall remain in place until after the seal coat has been finished.

"**Prevention of Dust.** The shoulders of the road and adjacent grounds shall be sufficient sprinkled during the placing of bituminous material wherever there would otherwise be danger of clouds of dust blowing over the pavement.

"**Laying Bituminous Concrete.** The bituminous concrete, heated and prepared as specified, shall be delivered direct from the mixer to the point of deposition on the foundation in trucks or wagons, provided with canvas covers for retaining the heat. As delivered the bituminous concrete shall have a temperature of at least 66° C (150° F). Material having a lower temperature than this shall not be laid upon the foundation. The hot bituminous concrete shall be dumped upon platforms, constructed as directed, and shoveled with hot shovels into position on the foundation. The bituminous concrete shall be immediately uniformly spread over the foundation course by men experienced in such work and thoroly compacted by rolling. When compacted the wearing course shall have a thickness at no place of less than 2 in and shall be free from surface depressions and irregularities. The paving shall be done as continuously as practicable, to reduce to a minimum the number of joints between hot and cold materials. Such joints shall be constructed as directed.

"**Rolling.** The bituminous concrete wearing course, laid as specified above, shall be rolled at once, while the mixture is warm and pliable, beginning at the edges and

working toward the center. Means for preventing the bituminous material from adhering to the roller without injury to the bituminous concrete, shall be provided. Rolling shall continue without interruption until all roller marks disappear and the surface shows no further compressibility. Places which the roller cannot effectively reach shall be compacted with hot iron tampers.

" **Roller.** Rollers used on the bituminous concrete shall be well balanced, self-propelled, tandem rollers, weighing between 10 and 12 tons each. Each shall have a compression under the rear roller of between 250 and 350 lb per lin in of roll, and shall be provided with an ash pan, which shall prevent ashes from dropping onto the bituminous concrete or seal coat.

" **Testing.** Before placing the seal coat, the surface of the bituminous concrete shall be tested with a 4-ft straight edge laid longitudinally upon any portion of the surface, and any depression or other irregularity exceeding $\frac{3}{8}$ in shall be satisfactorily eliminated.

" **Seal Coat.** As soon as possible after the compaction of the bituminous concrete, when the surface is clean and dry, a seal coat of the hot asphalt cement shall be evenly distributed over the bituminous concrete and uniformly spread by means of squeegees. The asphalt cement shall be applied at a temperature not less than 135° C (275° F), nor more than 177° C (350° F), at a rate of $\frac{1}{2}$ to 1 gal per sq yd, as directed. A thin, uniform layer of dry, clean broken stone chips shall be immediately uniformly spread in two applications over the asphalt cement by machines or skilled workmen. Each application of broken stone chips shall be rolled twice by a self-propelled, tandem roller. The spreading of the broken store chips shall not lag more than 20 ft behind the placing of the asphalt cement coating. Broken stone chips shall not be placed on the wearing course before the asphalt cement of the seal coat is applied. The surface of the bituminous concrete shall be kept scrupulously clean until the seal coat is applied, and the contractor shall not permit any hauling over the wearing course before the completion of the seal coat.

" **Broken Stone Chips.** Broken stone chips shall consist of the product of a stone crushing plant obtained by passing the broken stone thru a section of a rotary screen having circular openings $\frac{3}{8}$ or $\frac{1}{2}$ in in diameter and over a screen having openings of $\frac{1}{8}$ or $\frac{1}{4}$ in.

" **Seasonal and Weather Limitations.** No bituminous concrete shall be mixed or placed when the air temperature in the shade is below 10° C (50° F).

" **Measurement and Payment.** The quantity of bituminous concrete wearing course to be paid for under this item shall be the number of square yards, measured horizontally, satisfactorily completed in accordance with the specifications. The price stipulated in this item shall include the furnishing, crushing and screening of the broken stone, including the broken stone chips for the seal coat, and heating, mixing, placing and rolling of the broken stone and the asphalt cement or refined tar, and all work and expenses incidental to the completion of the bituminous concrete and the seal coat, except the furnishing of the bituminous cement, which will be included for payment under the item Asphalt Cements and Refined Tars for Wearing Course of Bituminous Concrete Pavement or the items Asphalt Cements and Refined Tars for Wearing Course of Bituminous Concrete Pavement and Asphalt Cements for Seal Coat for Bituminous Concrete Pavement. Measurement under this item shall not include any pavement repaired or relaid, except as provided for in the following paragraph.

" **Removing and Replacing Wearing Course.** If the contractor removes, as directed, portions of the wearing course, and the work thus exposed for examination is found satisfactory, or if for any reason he shall be ordered to remove wearing course built in full accordance with his contract, he shall be paid for such excavation one-fourth the price per square yard stipulated in this item. If the wearing course after examination is found to be of acceptable quality, the original wearing course will be paid for as well as that used to refill the excavation. In connection with the removing and replacing of the wearing course in accordance with this paragraph, no quantity shall be measured as less than 1 sq yd."

Road Board of England Specifications for Bituminous Concrete Pavement Having a Mineral Aggregate Composed of Broken Stone or Slag.

" **Foundation.** Any road which is to be surfaced with tar macadam (Class A tar concrete) should have a proper foundation or sub-crust of adequate thickness to bear the traffic likely to use it. Before laying a new surface of tar macadam the thickness of

the old crust, including foundation, should be ascertained by opening trial trenches at intervals averaging about 150 yd extending from the haunch of the road to the center, such trenches to be made alternately on opposite sides of the road.

"The Thickness of the Surface Coating of tar macadam when consolidated by rolling should be from 2 to 3 in, according to traffic requirements. For a greater thickness than 3 in the material should be applied in two coats. In the case of naturally hard sub-soils, not materially softened by infiltration of surface water, the total thickness of the road crust, including foundation, if any, after consolidation of the new surface of tar macadam by rolling, should not under ordinary circumstances be less than 6 in, unless the sub-soil is so hard as in itself to act as a good foundation, in which case the thickness of the road crust may be reduced to 4 in. In the case of clay or other yielding sub-soils the total thickness should not be less than 11 in.

"Cross-Section. The finished surface should have a cross-fall of about 1 in 32. If the crust is not sufficiently thick at the crown to enable this cross-fall to be obtained with a new coating of the thickness above mentioned, then the old surface should be left intact and unscarified, and the thickness of the new coat of tar macadam increased as far as may be necessary. If the crust is of sufficient thickness for the purpose, the regulation of the cross-fall should be carried out by scarifying the surface and removing material from the crown to the sides previous to the application of the new coating. The material loosened by scarifying should be screened and all finer material than ½ in should be thrown aside.

"The Aggregate of the new surface of tar macadam should be composed of broken stone of approved quality, or selected slag of approved quality, and should contain at least 60% broken to the size of 2½ in, not more than 30% of from 2½ to 1¼ in, and 10% of ¾ to ½ in for closing. The last-mentioned size should be kept separate and used as top dressing during rolling operations. The stone used must be thoroly dried before being coated with tar.

"Tar Cement. For making tar macadam, tar should be used which complies with Road Board Specification Tar No. 1, or Road Board Specification Tar No. 2 (see Sect. 14, Art. 5), the choice being determined by the circumstances of each case. If tar No. 1 has been used for tarring the stone, care should be taken, especially in hot weather, that the tarred material has been allowed to stand for a sufficient length of time to allow the tarred surface of the stones to become partially hardened and in a tacky condition. If tar No. 2 has been used for tarring the stone, the macadam should be laid soon after being tarred, and if the tar be of the heavier grade of this quality the stone coated with such tar should only be laid when the road is quite dry and in warm sunny weather. The quantity of tar used, to coat 1 ton of stone, should be approximately from 9 to 12 gal, varying according to the sizes of the stone, the grade of tar used, the method of mixing and other conditions.

"Laying and Rolling. The tar macadam, after having been spread and levelled, should be rolled into a smooth surface, but too much rolling should be avoided. Less rolling is required than in the case of water-bound macadam. A 10-ton roller is a suitable size for use in most cases, but good results can be obtained by using a 6-ton roller and finishing with a 10-ton roller.

"Seal Coat. In order to get the best results from the use of tar macadam, it is advisable to apply a coating of tar to the surface after the road has been used by traffic for several weeks. This tar should comply with the provisions of Road Board Specification for Tar No. 2, and should be poured or sprayed on the surface at a temperature of about 132° C (270° F). Stone chippings, crushed gravel, coarse sand or other approved material, free from dust, not larger than will pass thru a ¼-in sq mesh, should be used for gritting in quantity not exceeding 1 ton for 300 to 350 superficial yd, if grit is used, and 1 ton for 200 to 250 superficial yd if coarse sand is used."

Tarmac Pavement Specifications, as used in some districts in England, are as follows:

The Crossfall for Tarmac pavements shall be 1 in 32, or about ⅜ in to 1 ft.

Laying. "The Tarmac shall be applied in two layers, the bottom layer consisting of 2¼-in gauge, the top layer of 1½-in gauge. Each layer shall be separately consolidated with a roller of about 8 to 10 tons in weight. The surface of the top layer consolidation should be well sprinkled with ⅝-in material, so as to fill all interstices, and again rolled to complete consolidation and an even and water-tight surface, being

afterwards blinded with slag or other suitable grit at the rate of 1 ton to every 250 sq yd of road surface. The thickness of each coat, for a total thickness of 3 in, shall be 2 in for the bottom coat and 1 in for the top coat; the proportions of gauges required being 5 of 2¼-in, 4 of 1½-in, and 1 of ⅜-in.

Maintenance. "It is recommended that, generally speaking, once during the first 12 months after completion, the roadway shall be swept clean of all surface matter, and painted with refined tar at the rate of about 7 sq yd to 1 gal, and blinded with suitable slag or other chippings ⅜-in down to dust, at the rate of 1 ton to every 200 yd of surface. This painting should again be carried out during the third year after completion."

14. Construction of Class B Pavements

The methods of mixing and laying Class B bituminous concretes are similar to those described and discussed as applicable to Class A bituminous concretes, except that hand mixing methods should never be employed. The mixing and laying of combinations of broken stone, sand and filler, or similar materials, must be carried on with exceptional care in order to prevent the segregation of the different sizes of the aggregate. The plants employed include all the machines described in Art. 11. To secure the best results, the plant should have a rotary drier, a pug-mill mixer, and, preferably, storage bins and weighing devices. For details of operation of portable, semi-portable and stationary plants, see Art. 11 and Sect. 17, Arts. 13 and 14. Methods of laying are discussed in examples of construction given in this Article, in Art. 12, and in Sect. 17, Art. 15, and are described in detail in the specifications cited in Art. 15. For methods of constructing AMIESITE and FILBERTINE pavements, see Art. 15.

Construction of Class B Pavements in Washington, D. C. by Brooke (23b). For description of mineral aggregates used, see Art. 6.

"The paving mixture is prepared in a sheet-asphalt paving plant. The sand and stone after being heated in separate driers to about 149° C (300° F), are conveyed to the box used for mixing binder stone where the hot asphaltic cement and cold limestone dust are added and the whole thoroly mixed. The method of laying is described in the specifications as follows: The mixture will be hauled while hot to the site of the work and shall be covered until deposited on the street. The temperature at the time of dumping shall not be less than 104° C (220° F). The hot mixture shall be evenly spread with hot tools upon the base to such a thickness as will make a layer 2 in in thickness after rolling. It shall then be rolled with a steam roller, weighing not less than 1 ton per ft of tread of roller until no further compression occurs. After the rolling of the asphaltic concrete wearing surface has been completed, there shall be spread over such surface a thin coating of asphaltic cement, as used in the surface, not to exceed on an average ¼ gal to the sq yd, of such consistency as shall be approved, which shall be thoroly brushed into the wearing surface so as to fill all voids and smooth out any minor unevenness of the said surface. There shall be spread over and rolled into this flush coat a thin layer of trap screenings, so far as practicable devoid of dust, in size from ⅜-in down, to secure a gritty, non-slippery surface.

"The asphaltic concrete, particularly if there is a slight excess of cement, tends to separate during the haul to the street, the fine material and cement working to the bottom of the wagon. In cold weather it is essential that the material arrive on the street amply hot, as the slightest chill stiffens it and makes it very difficult to spread and roll. For these reasons, aside from other considerations, motor trucks have been found to be better than carts or wagons for the hot haul.

"Some difficulty has been experienced in applying the flush coat in sufficient quantity to seal the surface without causing the formation of a mat which would cover up the stone aggregate and produce a slippery surface. The specification originally provided for the application of a thin coat of hot asphalt cement. On several streets the hot cement used in the paving mixture was tried. On one street this surface was so objectionable that it has been necessary to sand it each summer. The effect of the coarse sand and the partial wearing off of the mat and consequent exposure of the stone are

gradually curing this slipperiness. After this experience the hot application was abandoned for an asphaltic emulsion which is applied cold, broomed in, and then covered with chips. After the evaporation of the water and emulsifier, ammonia, a light coating of asphalt is left. This method gives the rough mosaic surface which is desired but it is questionable if there is sufficient body of cement to bind the fine material and effectually seal the surface. It is believed it would be practicable to obtain a satisfactory flush coat by applying a lighter cement with a power distributor, such as used in macadam surface and penetration work, and the engineer department intends to try this method.

"The average price of this pavement laid to a thickness of 2 in after compression, including a 6-in gravel concrete base and grading for same, has been \$1.79, which includes a 5-year guarantee. The average price for the pavement without base has been \$0.97, including guarantee. The average cost of macadam base has been \$0.345, making cost of bituminous concrete pavement on macadam base, \$1.31."

Details of Construction of Class B Bituminous Gravel Concrete Pavement, built in 1916 on the Alexandria-Accotink Road, Fairfax County, Va., under the direction of the U. S. O. P. R. (67d). The pavement is 24 500 ft long and has an area of 38 443 sq yd. For details of construction cost data, see Art. 21.

The Aggregate consisted of crushed and screened gravel; coarse aggregate passed 1¼-in and was retained on ¼-in circular openings; fine aggregate passed ¼-in circular openings, and contained less than 5% of clay; ordinary ground limestone was used as a filler; washed Potomac River gravel, screened thru ½-in and over ¼-in screen was used as top dressing for seal coat.

Mixing. The mixing plant was of the stationary type, operated by steam power. The gravel was excavated by hand, run thru a jaw crusher, and screened to remove tailings before it was heated. The heating was done in two rotary drums, wood being used as fuel. The fine and coarse aggregates then were separated by means of a ¼-in screen and stored in two bins immediately over the mixer. The asphalt cement, having a penetration of 64 at 25° C (77° F), was heated in two kettles supplied with steam coils, and the mixing was done in an ordinary twin pug mixer. The average time for mixing a batch was 1 min. Analysis of 61 plant samples of mix gave the following averages: Bitumen, 6.5%; aggregate retained on ¼-in screen, 54.5%; aggregate passing ¼-in screen and retained on a 200-mesh sieve, 35.8%; aggregate passing 200-mesh sieve, 3.2%.

Laying. The hot mix was dumped from the trucks or wagons onto a steel dumping board and spread with hand shovels and asphalt rakes. Then it was set by rolling with a 2½-ton tandem roller and compacted to its final shape with an 8-ton tandem roller. The loose depth of the hot mix averaged about 2¾-in, and the compacted depth was not less than 2 in. The temperature at which the material was spread ranged from 93° to 149° C (200° to 300° F).

The Seal Coat was of the same asphalt used in the mix, covered with pea gravel. The asphalt was spread at a temperature of about 177° C (350° F), about ⅛ gal per sq yd being used. The pea gravel was spread at the rate of about 1 cu yd to 150 sq yd of surface. After the gravel was spread the surface was rolled with the 8-ton tandem roller.

15. Specifications for Class B Pavements

Mineral Aggregate of Broken Stone or Gravel, Sand and Filler. Ill. State Highway Dept. 1917 Specifications, in abstract.

"Tests for Broken Stone. The crushed stone shall be hard and sound and shall have a coefficient of wear according to the Duval test of not less than 8 when used for the second course, and of not less than 6 when used for the lower course only. If the cementation value of the stone is less than 25, a good bonding gravel or other material satisfactory to the engineer shall be used as a binder for the lower course of stone. Slag or similar material may be used subject to the approval of the engineer. All tests shall be made in accordance with the methods outlined in Bul. 44 of the U. S. O. P. R., Washington, D. C.

"The Size of Crushed Stone that shall be used is as follows: Broken to a size that will pass over a ½-in ring and will just pass thru a 1½-in ring, which size will hereinafter be referred to as 1½-in stone. Not less than 30% nor more than 80%

of this stone shall be retained on a ¾-in ring. This stone shall be clean and entirely free from dust.

"Gravel may be used instead of the size of stone designated above providing it complies with the following requirements for the respective sizes and consists of hard materials meeting the approval of the engineer: Ranging from a size that will pass thru a 1½-in ring and will pass over a ⅝-in ring, which size will hereinafter be referred to as 1½-in gravel. Not less than 25% nor more than 75% shall be retained on a ¾-in ring and at least 30% of the gravel shall be crushed material. Gravel deficient in crushed material may be used mixed with crushed stone when approved by the engineer. All 1½-in gravel shall be entirely free of dust, clay, loam or organic matter.

"The following size of gravel shall be used on all contracts: Ranging from a size that will pass thru a ⅝-in ring and graded to fine sand, which size will hereinafter be referred to as grit sand. Not less than 40% nor more than 80% of the grit sand shall pass thru a 20-mesh sieve. It shall consist of hard grains and shall not contain more than 2%, by dry weight, of clay or organic matter.

"**The Filler** used in the bituminous concrete shall be a Portland cement, limestone, or silica ground to a fine dust, at least 75% of which will pass a 200-mesh sieve, and at least 95% of which will pass a 50-mesh sieve.

"**The Second Course** shall consist of 1½-in stone, grit sand and filler which have been mixed with the bituminous material in a suitable power mixer at the temperature prescribed by the engineer.

"**Bituminous Aggregate.** In order to obtain a dense concrete, the 1½-in stone, grit sand, filler and bituminous binder shall be used in the proportions required by the engineer, but unless otherwise instructed, the contractor shall mix the stone and the grit sand in the ratio of 2½ cu yd of stone to 1 cu yd of sand, and they shall be thoroly mixed with 150 lb of filler per cu yd of stone, and not less than 30 nor more than 33 gal of the bituminous material per cu yd of stone. Should the bituminous binder meeting the requirements of specifications A contain less than 95% of bitumen, then enough binder shall be used to furnish not less than 30 nor more than 33 gal of the bitumen per cu yd of stone, and the quantity of filler used shall be decreased to the amount required by the engineer. The engineer shall be permitted to take samples of the bituminous aggregate at any time to determine if the materials have been mixed in the required proportions.

"**Seal Coat.** After rolling, a seal coat of ⅓ to ½ gal of the bituminous binder shall be applied at the temperature prescribed by the engineer. It shall be covered immediately with just enough grit sand to prevent it from sticking to wheels, and then rolled. The road shall be allowed to stand for at least ½ day before being opened to traffic."

Mineral Aggregate of Broken Stone, Slag or Gravel and Filler. W. Va. State Road Comm. 1917 Specifications, in abstract.

"**Aggregates.** The fine and coarse aggregates shall consist of approved stone, slag, or gravel passed thru a stone crusher and crushed so that all particles will pass a screen having circular openings 1¼ in in diameter. The product of the crusher shall be passed over a screen having circular openings ¼ in in diameter and that part of the product which passes this screen is designated fine aggregate, while that part of the product which fails to pass a ¼-in screen is called coarse aggregate. The coarse aggregates shall not contain an appreciable amount of clay, loam, or soil, and the fine aggregate shall not contain more than 5% by weight of such material.

"**Filler.** The filler shall consist of limestone dust or Portland cement, and shall be of such fineness that all will pass a 30-mesh sieve and not less than 66% will pass a 200-mesh sieve.

"**Mixing.** The bituminous concrete shall consist of from 40 to 60% by weight of coarse aggregate, from 30 to 45% by weight, of fine aggregate, from 3 to 5%, by weight, of filler, and from 6 to 8%, by weight, of bituminous material, the exact percentages of each to be furnished by the engineer from time to time as the work progresses. The fine and coarse aggregate may be mixed together in approximately designated proportions, and shall be heated in a rotary drier to a temperature of 149° to 177° C (300° to 350° F), and when still hot shall be separated into sizes designated for fine and coarse aggregates, the fine aggregate and coarse aggregate passing into separate bins. From these bins and before the aggregates have materially cooled,

the required amount of each aggregate for a batch shall be dropped into an approved mixer. The required amounts of filler and hot bituminous material shall then be added, and the whole thoroly mixed until all particles of the aggregate are coated with the bituminous material."

Amiesite Pavement: Penn. State Highway Dept. 1917 Specifications.

"**Asphalt.** The asphalt used in this type of pavement shall conform to the following specifications: Specific gravity not less than 1.00; solubility in carbon disulphide not less than 99%; penetration at 25° C (77° F), 100 g, 5 sec, Dow method, not greater than 175 and not less than 125, and after heating 5 hr at 163° C (325° F), a 50-g sample shall show a penetration at 25° C (77° F), 100 g, 5 sec, Dow method, not less than 50% of the original penetration; the ductility at 50 penetration shall be not less than 50 cm.

"**Mineral Aggregate.** Mineral aggregate for the bottom course shall be clean, crushed rock of approved quality run of crusher passing a 2-in screen and being retained on a ¼-in screen, free from foreign materials. The French coefficient of wear shall be not less than 12. Mineral aggregate for the top course shall be similar, except that all of it shall pass a ⅝-in screen and be retained on a ¼-in screen.

"**Filler.** The filler shall be clean, crushed rock screenings of approved quality, all passing a ¼-in screen.

"**Mixing.** The mineral aggregate shall be treated with a liquefier to make the asphalt adhere. The asphalt heated to approximately 135° C (275° F) then shall be added and after the mineral aggregate is coated thoroly, ground oxide or hydrate of lime shall be added. The ingredients referred to above shall be mixed in the following proportions:

	Bottom Course	Top Course
Mineral aggregate	86 to 90%	86 to 90%
Filler	4 to 6%	5 to 8%
Asphalt	5 to 6%	5 to 7%
Lime	½ to 1%	½ to 1%
Liquifier	½ to 1%	½ to 1%

"**Unloading Surface Mixtures.** When necessary, the Amiesite may be steamed to facilitate its unloading from cars. Steam pressure shall not exceed 15 lb to the sq in and the Amiesite shall not be steamed more than 15 min in any one place. This work shall be done under the supervision of the inspector in charge.

"**Delivery of Surface Mixtures.** Amiesite surfacing materials shall be delivered upon the work in tight vehicles, cleaned previously of all foreign materials. The surfacing materials shall be unloaded from the wagons upon iron sheets or boards at such distance from the point of spreading that all the mixture will be turned completely in distributing it to place. The dispatching of vehicles shall be arranged so that all material delivered may be placed and shall have received initial rolling in daylight.

"**Placing Wearing Surface.** The bottom course shall be spread in a uniform layer of not less than 2¼ in in depth when measured loose, using blocks or strips to insure an even distribution, and then rolled thoroly. If any depressions appear they shall be filled with Amiesite and rolled until the surface is even and to the grade desired. After this preliminary rolling the top course shall be applied, not less than 1 in in depth, loose measurement, and raked to an even depth so as to cover the underlying bottom course and fill the voids. The bottom course in no case shall be spread more than 300 ft in advance of the top course, nor more than 50 ft of the bottom course shall be left uncovered during the night. The total compressed depth of finished Amiesite surface shall be not less than 2 in.

"**Conditions for Placing.** No Amiesite shall be spread when the road-bed contains depressions holding water. The Amiesite shall be kept clean at all times. Dirt or other foreign material shall not be allowed to mix with, under, or on the Amiesite while being unloaded from cars, spread and rolled. Should the bottom course become

coated or partly coated with dust or dirt before the top course can be applied, the part thus coated shall be swept and then given a light application of bituminous cement that can be applied from a sprinkling pot so constructed that a thin and uniform application can be made easily.

" **Rolling.** After the top course has been spread evenly to grade, the surface shall be rolled with a power roller of at least 8 tons weight until the material is compacted thoroly and ceases to creep in front of the roller. The rolling shall start from the side lines of the street or road and work toward the center. Care shall be taken that the shoulders are firm and solid, as otherwise the surface mixture will iron out to a feather edge and crack. No rolling shall be done unless the Amiesite is free from water. The road shall be rolled also diagonally and transversely, the amount of these rollings equalling the longitudinal rolling.

" **Surface Finish.** After this rolling is finished, approved, clean, dry sand or approved fine stone screenings passing a ¼-in screen shall be spread in a thin layer and rolled. The road then may be thrown open to traffic. The finished surface shall conform with the grade and cross-sections given."

Filbertine Pavement: Penn. State Highway Dept. 1917 Specifications.

"**Asphaltic Cement.** The asphaltic cement shall be known as R. Y. Filbert's Improved Waterproof Filbertine Paving Cement and shall comply with paragraphs 158 and 159. The penetration of the asphaltic cement 100 g, 5 sec, 25° C (77° F), shall be 50 to 65, as directed.

" **Composition and Preparation of Mixture.** The mineral aggregate in the Filbertine mixture shall be composed of sound, hard, crushed trap rock, having a French coefficient of wear of not less than 12, or other approved stone having a French coefficient of wear of not less than 10; sand such as required for asphaltic wearing surface mixture, paragraph 160; and stone dust or Portland cement, which shall be combined with the asphaltic cement within the following proportions best suited for making a dense mixture:

Bitumen	6 to 8%
Filler, stone dust, or Portland cement	4 to 6%
Stone, ¾-in hard crushed	55 to 60%
Sand	30 to 35%
Other ingredients	not more than 1%

" **Delivery of Surface Mixture.** Filbertine mixture shall be delivered upon the work in tight vehicles previously cleaned of all foreign materials. The vehicles shall be covered with canvas of sufficient size to protect the entire load and shall be dispatched so that all materials delivered may be placed and shall have received initial compression in dayligh .

" **Placing.** The mixture, on reaching the work, shall be deposited outside of the area on which it is to be spread and then shall be spread on the prepared foundation by suitable means to proper depth, the whole of the mixture being turned completely in distributing to place.

" **Rolling.** Initial compression shall be effected with a tandem power roller, weighing approximately 2½ tons, having a main roll of such width as to give a compression of approximately 125 lb per in width of tread, and final compression shall be effected with a power roller of at least 8 tons weight. The rolling shall include complete transverse and an equal amount of longitudinal rollings and two diagonal rollings approximately at right angles one to the other. Hot iron tampers shall be used where the roller cannot be used. The rolling and tamping shall be continued until the resultant wearing surface is compressed thoroly and is dense, slightly elastic, firm without brittleness, and durable. The wearing surface as thus constructed shall have a depth of not less than 2 in after ultimate compression.

" **Seal Coat.** Immediately after the initial compression and while the surface is still hot, a prepared seal coat shall be applied uniformly and in such a manner as to fill thoroly all the surface voids in the Filbertine mixture and not to leave a coating of more than ¼ in on the surface of the pavement. The seal coat mixture shall consist of finely graded sand, as required for asphaltic wearing surface, paragraph 160, coated with 9.5% to 10.5% of bitumen by weight. Asphaltic cement as previously specified shall be used in the seal coat mixture. The mixing shall be done in a suitable me-

chanical mixer. The seal coat mixture shall be rolled at once and thoroly into the Filbertine mixture so as to form a perfect bond and the finished surface shall be firm and true to crown and cross-sections."

16. Construction of Class C Pavements

The methods of mixing bituminous concretes of Class C vary to a marked degree on account of the radical differences in the characteristics of the mineral aggregates and the products of bituminous concrete which are included in this classification.

Topeka and Bitoslag Pavements. The methods of mixing and laying are similar to those described in Art. 14 as applicable to the construction of Class B pavements. As the maximum size of the mineral aggregate used in the Topeka mixture passes a ½-in screen and the maximum size of the slag aggregate of the Bitoslag bituminous concrete passes a ¼-in screen, and furthermore, as the general composition of the aggregates are somewhat similar, the methods of construction of these pavements may be identical. To secure the best results, the mixing plant should have a rotary drier, a pug-mill mixer, storage bins and weighing devices. In order to readily secure uniform mixtures of bituminous concrete, the plant should have a screen by means of which the aggregate may be separated into fine and coarse aggregates, deposited into two bins and separately weighed. For details of operation of portable, semi-portable and stationary mixing plants, see Art. 11 and Sect. 17, Arts. 13 and 14.

Laying. Methods of laying are discussed in the examples of construction given in this Article, in Art. 12, and in Sect. 17, Art. 15, and are described in detail in the specifications cited in Art. 17.

Seal Coats. Practice varies relative to the use of seal coats on Topeka pavements. The efficiency of seal coats depends mainly upon the kind of aggregate, and the amount and character of the traffic. Based on service tests, it does not appear that Bitoslag pavements, which have a finer aggregate than Topeka, require bituminous seal coats. Generally, it will prove economical to use seal coats on Topeka pavements subjected to horse-drawn commercial traffic as the blows from horses' shoes may dislodge ¼ to ½-in particles of aggregate in the surface of the pavement. In cases where gravel is used for the coarse aggregate, it is always advisable to use a seal coat to prevent the particles of gravel from pitting out. Seal coats on Topeka wearing courses should be thin and uniform in amount. The method of application must be varied to suit the characteristics of different kinds of bituminous cements. For example, a tar cement can readily be applied by hand-drawn gravity or pressure distributors or pouring cans and further distributed by brooms, mops or squeegees, whereas some asphalt cements used with Topeka aggregates would require mixing with a flux before it would be practicable to distribute them in as small an amount as ⅛ to ¼ gal per sq yd. These seal coats are completed by a thin application of coarse sand, fine gravel, or stone chips, which is thoroly rolled. Topeka pavements, which are not finished with a seal coat, and Bitoslag pavements are completed by the application over the thoroly rolled wearing course of a thin dressing of Portland cement or other fine mineral matter. Topeka pavements thus finished have proved satisfactory when subjected to traffic composed mainly of motor vehicles.

Form for Daily Report on Modified Topeka Mixture by Mullen (49b), giving data relative to one sample taken during the construction of the St. Augustin-Quebec Road in the Province of Quebec, Can.

FORMULA OF MANUFACTURE	POUNDS	PER-CENT	SAMPLE OF ASPHALT MIXTURE	
ASPHALT CEMENT	100	10		taken at mixer of plant of
FILLER—STONE DUST	120	12		LAGANIERE, HOUDE & CO., ST. FOY,
FILLER—PORTLAND CEMENT				by Mr. Abias Pepin, C. E.,
SAND FROM COLLECTOR				10:00 A.M., FRI., OCT. 12, 1917.
SAND FROM HEATING DRUM	570	57		Mixture going to surface
4-MESH STONE HEATING DRUM	210	21		SAINT AUGUSTINE - QUEBEC ROAD
2-MESH STONE HEATING DRUM			REMARKS:	A very good mixture.
TOTAL BATCH OF MIXTURE	1000	100		

TEST NO.	M-2560	RESULTS OF TESTS OF SAMPLE SUBMITTED				MODEL MIXTURE		VARIATIONS	SPECIFICATIONS Min.	Max.	TOTALS
BITUMEN		10	2	10	2	10	10		8	12	
PASSING	HELD ON	NOTE: Figures show percentages by weight.									
200	MESH	10	0	10	0	10	10		7	14	Not Less Than 18
100	200	16	3			9					
80	100	3	0	19	3	9	18		7	25	
50	80	11	3			16			3	25	11 to 36
40	50	11	1	22	4	7	23		3	18	
30	40	6	7			6			3	14	7 to 25
20	30	2	6			4			3	9	
10	20	5	2	14	5	2	12		2	6	
4	10	15	0			18			11	25	20 to 35
2	4	8	6	23	6	9	27		4	10	
	2								PENETRATION OF ASPHALT CEMENT		60
TOTALS		100	0	100	0	100	100	TEST RUN BY	G.		

Topeka Tar Concrete Pavements by Sharples (59). "In Pittsburgh, Pa., many streets were laid from 1890 to 1898 under the name of Vulcanite pavement, using coal tar pitch or a mixture of coal tar pitch and asphalt as a bituminous cement. The mineral aggregate varied greatly in different streets but might be said to follow in general the Topeka mix. Lang Ave. is an example of the true Topeka mix and was laid in 1892. The cement used was 49° C (120° F) melting point coal tar pitch, about

30% free carbon, with some small percentage of Trinidad asphalt. The street is residential with a residential street traffic and would be classed as in good condition at the present time (1914), with only nominal repairs during its 22 years of use.

"Much of the early tar concrete work in New England resembles closely Topeka mix with the ½-in crushed stone replaced by pebbles. The following screening analyses of typical New England tar-concrete sands show that sands in Newton and Brighton, Mass., fall within the Topeka specification.

Mineral Aggregate	Topeka	Newton	Brighton
Passing 200-mesh	5 to 11%	4.9%	5.0%
Passing 40-mesh	18 to 30%	24.8%	18.5%
Passing 10-mesh	25 to 55%	55.0%	54.8%
Passing 4-mesh	8 to 22%	12.4%	17.1%
Passing 2-mesh	less than 10%	2.9%	4.6%

"The percentage of tar cement used in New England is usually larger than called for in the Topeka specification. The exact amount is varied to suit the particular sand used, but often runs as high as 12%. It was believed that a large excess provided a reservoir of tar cement which was drawn upon as needed. It would seem from more recent work that a smaller percentage of refined tar in the mix with provision for seal coats as needed would be more economical in the long run. Based upon this principle, work has been done with as little as 6% cement. With this small percentage, it has been definitely proved that a seal-coat protection is a necessity. Eight percent would seem to be a better starting point, and modifications in the percentage should be made to suit local conditions.

"A study of successes and failures in New England tar concrete shows that the requisites for success in using coal tar cement in Topeka mix are:

1. Carefully prepared foundations with due attention to drainage.

2. Suitable sands. Either too fine or too coarse sands are to be avoided. A sharp sand gives better results than rounded grains and a mineral aggregate which has structural strength in itself is to be aimed at.

3. A carefully prepared straight-run coal tar cement with a melting point of 38° to 49° C (100° to 120° F), ½-in cube method in water, varied to suit traffic conditions and local mineral aggregate available.

4. Careful handling of the coal tar cement. Coal tar cement, like other bituminous materials, is easily changed by heating to a high temperature or by holding a long time at a comparatively low temperature, 104° C (220° F), in open kettles. Refined tar, mineral aggregate, and the mix should be kept at or near 104° C (220° F). This point must be especially insisted upon when high melting point materials have previously been used.

5. Expert supervision is just as essential as in all other paving work. The exact method best for local handling, the exact percentage of bitumen required, the correct proportion of mineral aggregate, are matters requiring judgment and experience."

Bitulithic and Warrenite Pavements. The methods of operating Bitulithic and Warrenite plants for the manufacture, respectively, of Bitulithic and Warrenite bituminous concrete mixtures are fully described in Art. 11, and are discussed in Art. 7. Methods of mixing, laying and finishing Bitulithic bituminous concretes are covered in the requirements of the specifications cited in Art. 17, and described in examples of construction given in this Article.

Details of Construction of Bitulithic Pavement in Pierce County, Wash., by White (72). "The pavement has a 2-in Bitulithic top, 16 ft wide, containing 49 878 sq yd, laid on a 5-in 1:3:6 concrete base, with 6-in concrete curbs. The cost to the County was $1.445 per sq yd divided as follows: Subgrade and extras, including curbs, 23.4 cents; concrete base, 60 cents; Bitulithic top, 68.6 cents.

Mixing. "In the construction of this work a one-car asphalt plant was used by changing the sand bin into four compartments. The plant consisted of a rotary drum

to heat the sand and rock, oil being used for fuel, elevators to lift it into the elevated screens and separate it into the different sizes, and the bins into which the sand and rock passed after screening; there were three kettles, heated by coal and staves of the barrels that contained Bitulithic cement, in which the Bitulithic cement was heated, a weighing machine having a scale of seven beams, and weighing platform, buckets and mixing boxes. The crushed rock and sand were separately piled near the end of the rotary drum. A two-horse scraper was used to bring the rock and sand to the elevators where they were shoveled into the elevators which empty into the heating drum. It took about 4 min from the time the aggregate started in the drum to reach the bin. The rock was heated from 116° C (240° F) to 121° C (250° F). After leaving the drum the aggregate was lifted onto the screens which separated it into four sizes, passing into as many bins. No. 1 bin contained aggregate passing 10-mesh; No. 2 bin contained aggregate passing ¼-in screen and retained on 10-mesh; No. 3 bin passing ½-in screen and retained on ¼-in; No. 4 bin passing 1¼-in screen and retained on ½-in. The following proportions were generally used, tho some little variation was made to fit different materials: 315 lb, No. 1 bin; 90 lb, No. 2 bin; 140 lb, No. 3 bin; 440 lb, No. 4 bin; and 15 lb of dust finer than 200-mesh. This made 1000 lb of aggregate, to which was added 88 lb of Bitulithic cement heated to 121° C (250° F). These materials were carefully weighed, passed into a twin pug mill and thoroly mixed for about 1 min 40 sec, and then dumped into a wagon which stood underneath to receive it.

Laying. "It was hauled by teams and dumped onto the street, shoveled over until it was about the thickness required, raked to as smooth a surface as possible. It was then rolled with a 10-ton roller until thoroly smooth and no appreciable compression appeared, and it did not creep under the roller. If any low places developed, a little more material was put on to bring it to the required grade and thickness. After it was rolled, a squeegee car was used to spread the Bitulithic cement, which was heated in kettles on the street, and the top was thoroly coated with the Bitulithic cement, using approximately ¼-gal per sq yd, and then covered with hot screenings from the No. 1 bin with a little excess sand and put on by a sand-spreading machine using approximately 25 lb per sq yd. The pavement was then thoroly rolled with a 10-ton roller.

Organization. "The force required at the plant and the wages paid were as follows:

1 superintendent, furnished by the patentees	$200.00 per month;
1 foreman	100.00 per month;
4 feeders, 3 using shovels and 1 a hoe, to feed the aggregate into the elevators; 1 drum fireman; 1 boiler man; 1 hopper man; 1 mixer man; each	2.50 per day;
1 team	5.00 per day;
1 night watchman	3.00 per day.

From 3 to 13 teams, costing $5 per day, were used to haul the material.

"The street force was as follows:

1 foreman	$4.00 per day;
1 roller man	3.50 per day;
1 man, cleaning pavement	2.25 per day;
1 wagon dumper; 1 tamper; 5 shovelers; 2 rakers; 2 squeegee men; each	2.50 per day.

Warrenite Constructed with Oyster Shell Aggregate (27c). "An interesting example of the use of a bituminous surface, using oyster shell aggregate, may be seen on the Beckwith Neck Road connecting Cambridge and Hillspoint in Dorchester County, Md. The stretch of road improved, located about 1 mile beyond the town of Cambridge, was laid in five continuous sections, each section containing a different mixture, as follows: (1) Whole shells, crushed shells and bitumen; (2) whole shells, crushed shells, sand and bitumen; (3) whole shells, sand and bitumen; (4) crushed shells, sand and bitumen; (5) beach gravel, screened and graded with coarse sand, fine sand and bitumen, a check for use in determining the relative wear. The type of bituminous concrete is known as Warrenite and the surface was mixed and laid by the Warren Brothers Co.

"This surface was laid in the early summer of 1911. When inspected in Oct. 1913, the general condition of the surface was found to be good. In the sections where whole shells were used some of the whole shells which were near the surface with their flat sides up were cracked. The most satisfactory section was the one in which shell, crushed to pass a 1-in ring, sand and bitumen were used."

17. Specifications for Class C Pavements

Topeka Pavement, Am. Soc. Mun. Imp. 1917 Specifications. For specifications for subgrade, drainage and foundations, see Art. 4. For specifications for mineral aggregate, see Art. 8.

" General. On the foundation, as heretofore specified, shall be laid the bituminous concrete wearing surface, which shall consist of a mineral aggregate mixed with bituminous cement and laid as hereinafter specified.

"This wearing surface shall have a thickness of ...... inches after thoro compression with a roller. For heavy traffic a thickness of 2 in is sufficient for all practical purposes and in some cases will afford more stability than a greater thickness. For moderate and light traffic 1½ in will be sufficient thickness for the wearing surface when laid on a well constructed base as specified above.

" Method of Mixing. The aggregate shall be dried and heated in properly designated driers before mixing with the bituminous cement. The driers shall be of the revolving type, thoroly agitating and turning the materials during the process of drying. When the aggregate is thoroly dried and heated to a temperature of from 93° to 177° C (200° to 350° F), depending upon the bituminous cement used, it shall be immediately before cooling or exposure to moisture, mixed with the hot bituminous cement as hereinafter specified. If stone dust is used, it shall be introduced directly into the mixer without passing thru the drier. The bituminous cement shall be melted in a tank arranged so the heat can be properly and easily controlled and regulated. When melted and raised to a temperature of from 93° to 177° C (200° to 350° F), depending on the bituminous cement used, it shall be combined in the proper proportions with the hot aggregate and immediately mixed in a properly designed revolving mixer until a thoro and intimate mixture of the ingredients has been accomplished and the particles composing the aggregate are evenly and thoroly coated with the bituminous cement. The mixer shall not be exposed directly to the action of fire.

" Method of Laying. While still hot from the mixer, the paving mixture shall be spread evenly on the foundation with hot iron rakes and shovels, so that when compressed with the roller it shall have the thickness specified, with the surface even and true to grade. Along the curb and around manholes, catch-basins and other obstructions in the street, where the roller cannot reach, the compression shall be secured by the use of hot iron tampers. The rolling and tamping shall be done as quickly as possible after the material is spread, while still hot and pliable. When the paving mixture is hauled on the street in dump wagons it shall be, when ordered by the engineer, kept covered with canvas to retain heat, dumped on platforms and shoveled into place and raked to the proper grade. As soon as spread the paving mixture shall be rolled with a tandem roller weighing at least 6 tons and the rolling continued, working lengthwise and diagonally of the street. When practicable, additional compression in the wearing surface should be secured by the use of a 10-ton roller. Rolling must be steadily kept up and continued until all roller marks shall disappear and the surface gives indications of no further compressibility.

"The paving shall be done continuously, so the number of joints between the hot and cold material may be reduced to the minimum. When it is not practicable to lay it continuously and a joint is unavoidable, the edge of the cold material shall be trimmed down to a rough feather edge, and the surface, where the joint is to be made, painted over with bituminous cement, the hot material raked over the feathered edge and thoroly rolled. Instead of trimming the cold material, joint strips may be used consisting of strips of canvas about 18 in wide with 3 parallel lines of ¾-in ropes sewed on the under side about 3 in apart. The joint strips shall be laid on the feather edge of the freshly raked material with the upper rope at the line where the thickness begins to decrease and the rolling completed on top of the canvas as for finished pavement. The faces of the curb and gutter, iron castings, etc, shall be painted with bituminous cement before the paving mixture is laid.

" Surface Finish. As soon as possible after the rolling of the mixture is finished, and while the surface is still fresh and clean, and, if possible, while warm, a seal coat of bituminous cement of proper consistency to be flexible when cold shall be spread over the surface. It shall be applied while at a temperature of from 93° to 177° C (200° to 350° F), depending upon the bituminous cement used, and evenly spread with rubber squeegees or mops. Only a sufficient coat shall be spread to flush the

surface voids without leaving an excess. Immediately over this, a top dressing of torpedo sand, fine gravel or stone chips free from dust, which must be thoroly dry and heated in cold weather, shall be spread and thoroly rolled into the surface. A small surplus shall be left to be worn in or worn away by the traffic.

"In the case of park drives and roadways not subjected to heavy, constant traffic, and where a more grainy and coarse surface is desired, the surface finish specified above may be omitted and the following method of finishing adopted: As the bituminous concrete is raked to grade, and just before the roller comes on it, spread dry stone chips or coarse torpedo sand, evenly with swinging motions of a shovel, until the surface is barely covered. Then roll thoroly as specified in the preceding paragraph relating to method of laying. If bare spots appear under the roller, sprinkle more chips or sand and continue the rolling until the whole surface is fairly covered. After the sand or stone chips have worn into the surface the street shall be swept, all excess of surfacing material removed and the street left clean.

"**Asphaltic Cement and Flux.** Use the specifications for asphalt, asphalt cement and flux reported by the sub-committee on sheet-asphalt pavement specifications and adopted by the Society. See Sect. 17, Art. 12.

"**Coal Tar Cement.** The coal tar cement shall be the residue of the distillation of coal tar only, and shall be refined for the special purpose of making a paving cement. No mixture of hard pitch with the lighter oils of coal tar will be permitted.

"Its specific gravity shall be not less than 1.20 nor more than 1.29 at 21° C (69° F).

"The melting point determined by the cube method shall be not less than 38° C (100° F), and not more than 46° C (115° F).

"It shall contain not less than 15%, nor more than 30% of free carbon insoluble in benzol.

"It shall be free from water as determined by distillation and shall show upon ignition not more than 0.5% of inorganic matter.

"No distillate shall be obtained lower than 170° C (338° F), and up to 315° C (600° F) not less than 5% and not more than 20% of distillate shall be obtained. The distillate shall be of a gravity of not less than 1.03 at 15.5° C (60° F). The residue shall have a melting point of not more than 74° C (165° F). In making this distillation an 8-ounce glass retort shall be used and the thermometer suspended so that before applying the heat the bulb of the thermometer is ½ in above the surface of the liquid. The melting point of the pitch shall be determined by suspending a ½-in cube in a beaker of water 1 in above the bottom. The temperature shall be raised 5° per min from 15° C (9° per min from 60° F). The temperature recorded the instant the pitch touches the bottom shall be considered the melting point of the pitch. In testing the original materials the initial temperature shall be 4° C (40° F).

"**Water-Gas Tar Cement.** The specific gravity at 25° C (77° F) shall be between 1.155 and 1.170.

"On extraction with cold carbon disulphide at room temperature for 20 min, not less than 97.5% shall be soluble.

"When tested in a penetrometer at 25° C (77° F) with a No. 2 needle under 100 g load for 5 sec, it shall have a penetration of not less than 27.5 mm and not more than 32.5 mm.

"When 100 cm are distilled in a 250-cc Engler flask, according to the method proposed by the Am. Soc. Test. Mat., the loss by weight shall be within the following limits:

From start to 170° C	0
170° to 225° C	not over 0.5%
225° to 270° C	from 2 to 6%
270° to 300° C	from 5 to 9%
Residue	not less than 84%."

Modified Topeka Pavement: Wash. State Highway Dept. 1917 Specifications.

"**Materials and Equipment.** The materials and equipment necessary for laying this pavement shall conform in all respects to the material and equipment as specified for Standard Asphalt Pavement except as herein otherwise noted.

"**Crushed Rock or Gravel.** Crushed rock or gravel shall be made from clean gravel or stone, hard, durable and uniform in quality, which shall show a coefficient of wear

in excess of 10, as determined by the Deval abrasion test, and a hardness in excess of 15, as determined by the Dorry hardness test, all tests being under the conditions and methods employed in the U. S. O. P. R. The rock shall be crusher run and shall contain all the fine material, none of which shall be coarser than will pass a ½-in screen. It is further provided that where gravel is crushed for this work, no gravel shall be fed to the crusher smaller than 1 in in diameter.

"Crushed Rock Screenings. Crushed rock screenings shall be of the same quality of stone as above described, and so graded that all shall pass a ¼-in screen and all be retained on an 8-mesh sieve.

"The Mixture shall consist of sand, crushed rock or crushed gravel, ground rock or cement filler and asphaltic cement.

The grading of the finished pavement shall be as follows:

Rock passing ½-in screen, retained on ¼-in screen......	15	to 30%
Rock passing ¼-in screen, retained on ⅛-in screen......	7.5	to 15%
Sand passing 8-mesh sieve and retained on 200-mesh sieve	30	to 60%
Dust filler passing 200-mesh sieve....................	10	to 15%
Asphaltic cement......................................	7	to 11%

"The sand and crushed rock entering into the mixture must be thoroly dry. The sand, rock and asphaltic cement must be maintained at approximately the same degree of temperature at the time of mixing.

"The Sand shall be clean material, hard, durable, and uniform in quality, free from soft materials, mica or other deleterious matter and shall be graded within the following limits:

From 0 to 2% shall be retained on 10-mesh sieve;
From 1 to 5% shall be retained on 20-mesh sieve;
From 3 to 8% shall be retained on 30-mesh sieve;
From 5 to 13% shall be retained on 40-mesh sieve;
From 7 to 17% shall be retained on 50-mesh sieve;
From 20 to 36% shall be retained on 80-mesh sieve;
From 8 to 16% shall be retained on 100-mesh sieve;
From 10 to 15% shall be retained on 200-mesh sieve.

"To insure the maintenance of an even grading in this mixture, three or more divisions must be made of the various sized particles in the aggregate.

"Proportioning. Proper proportions of these materials, together with the asphaltic cement, must be accurately weighed out, and the mixing so handled that each particle of this aggregate shall be thoroly and evenly coated with asphaltic cement, and an even distribution of the various sizes of aggregate in the mixture accomplished.

"This mixture shall be hauled to the street in suitable covered conveyances and shall be spread on the prepared, clean, dry base by shovelling and raking in a manner that will insure an evenly graded mixture that, when thoroly tamped and rolled, shall show an even true surface.

"Flush Coat. Over this shall be spread a thin even flush coat of asphaltic cement made by heating together refined asphalt and flux to a consistency of 140, Dow, at a temperature of about 93° C (200° F), this to be immediately followed by sweeping on an even coating of hot crushed rock screenings or coarse sand, all passing a ¼-in screen and retained on a 10-mesh sieve. The flush coat shall be applied with a suitable machine provided with a flexible band which will insure the quick, even spreading of hot material. Brooming will not be permitted.

"Rolling. The rolling shall be performed with 2½ and 8-ton rollers, continuously until the mixture is cold and in any case to continue for 2 hr after initial rolling. The final thickness of the asphaltic concrete wearing surface shall not be less than 2 in.

"Temperature. The temperature of the mixture at the time of placement in the street shall not be less than 93° C (200° F), and at no time shall it be greater than 149° C (300° F)."

Topeka Pavement, Using Bituminous Sand in the Mineral Aggregate: Cal. State Highway Dept. 1917 Specifications, in abstract.

"Paint Binder. While the concrete foundation is thoroly dry, it shall be cleaned to the engineer's satisfaction and its entire surface area coated with an asphaltic paint binder. The paint binder shall be applied with brooms in sufficient proportion and quantity to give a thin, uniform, black glossy film of asphalt which will harden

within 2 hr after application. The paint binder shall be composed of 1 part by volume of asphaltic cement of 80 to 90 penetration, to from 1 to 2 parts by volume, as directed by the engineer, of engine distillate of the lightest gravity of a quality approved by the engineer. The cost of the paint binder shall be considered as included in the price for asphalt surface.

"Asphalt Surface. Upon the concrete foundation prepared as above described and as soon as the paint binder has hardened shall be laid the asphalt surface, 1½ in in thickness, composed of broken stone or gravel, sand, stone dust and asphaltic cement or bituminous sand, the different ingredients being mixed in such proportion that the percentage composition, by weight, of the asphalt surface shall be within the following limits:

"Bitumen soluble in cold carbon disulphide between 7.5% and 10%.

"Broken stone or gravel, sand, stone dust and other inorganic ingredients, as follows:

Passing 200-mesh sieve, between 8% and 13%
Passing 80-mesh sieve, and rejected by 200-mesh sieve, between 14% and 25%
Passing 40-mesh sieve, and rejected by 80-mesh sieve, between 17% and 29%
Passing 10-mesh sieve, and rejected by 40-mesh sieve, between 5% and 11%
Passing 4-mesh sieve, and rejected by 10-mesh sieve, between 15% and 25%
Passing 2-mesh sieve, and rejected by 4-mesh sieve, between 3% and 10%
All to pass a 2-mesh sieve.

"At least 8% and not more than 17% of the asphalt surface mixture shall be stone dust.

"If the Surface Mixture is Prepared with Bituminous Sand, the following definitions, methods of preparation and tests shall be used.

"DEFINITION. The term bituminous sand shall herein be defined to mean a natural, solid mixture of silicious sand, with a heavy asphaltic petroleum, or heavy hydrocarbons mainly of an asphaltic nature, in which the sand shall predominate in quantity and with which may be naturally combined a small proportion of calcareous matter, infusorial earth, silicate of alumina, or trace only of other impurities not detrimental to the uses of the material as a proper road surfacing.

"PREPARATION. If the bituminous rock in its crude state fails in any particular to satisfy the tests hereinafter provided or the requirements of paragraphs (entitled Asphalt Surface) of this section it shall be crushed or disintegrated by suitable means and its deficiencies shall be corrected by the careful application of heat and by mixing therewith stone dust and sand or asphaltic cement, all of such character and in such proportions and manner as to insure a homogeneous mixture of all ingredients that will fulfil the said requirements and the following tests.

"TESTS. The total bitumen contained in the mixture as determined by solution in carbon disulphide shall be soluble in cold carbon tetrachloride to the extent of at least 97.5%, and in petroleum naphtha of 86° B to the extent of not less than 70% nor more than 90%. When 50 g of the mixture are heated for 5 hr at a uniformly maintained temperature of 163° (325° F) in a tin box 2½ in in diameter, after the manner officially prescribed, it shall not lose over 0.65% in weight."

Bitulithic Pavement: Am. Soc. Mun. Imp. 1917 Specifications. For specifications for subgrades, drainage and foundations, see Art. 4.

"Wearing Surface. On the foundation prepared as herein above specified, shall be laid the Bitulithic Wearing Surface and Seal Coat, described below, so as to have a thickness of 2 in after thoro compression. The wearing surface shall be composed of hard crushed stone, sand, and Bitulithic Cement.

"The Bitulithic Cement herein specified besides being produced under the direction, processes, supervision and laboratory inspection of, and with ingredients approved by Warren Brothers Co., shall in all respects comply with the specifications for Asphalt Cement contained in the Sheet-Asphalt Specifications of the Am. Soc. Mun. Imp. See Sect. 17, Art. 12.

"Preparation of Bituminous Concrete. Either of the two following methods and apparatus shall be used in the preparation of the wearing surface.

1. The stone and sand shall be heated in a rotary drier and, while still hot, separated into the desired number of different sizes by means of a rotary screen having a minimum screen opening of about 1/10 in and a maximum opening of about 1½ in. The openings in the successive screen sections up to ½ in size, shall not vary more than ¼ in and not more than ¾ in for the sizes larger than ½ in. The aggregate thus

separated shall pass into a bin having sections or compartments corresponding to the screen sections. From these compartments the aggregate shall pass into a weigh box, resting on a multi-beam scale. The desired amount of aggregates from each of the above compartments, shall be accurately weighed separately on the scale and the batch dropped into a twin pug mixer, where it shall be intimately associated and thoroly commingled with a predetermined quantity of Bitulithic Cement sufficient to coat all particles of the aggregate and to fill the voids in sand.

2. The stone and sand shall first be carefully measured as to sizes and a definite quantity of each size shall then be fed into an elevator terminating in a hopper or bin which discharges into a rotary drier or heater, both hopper and heater being so designed as to keep each batch by itself until heated. From the rotary heater the batch of mineral aggregate shall pass into a rotary cylindrical mixer containing blades, spirals or other devices for producing a uniform mixture of the mineral aggregate with a predetermined quantity of the Bitulithic Cement sufficient to coat all the particles of the aggregate and to fill the voids in same.

"The different sized particles of stone and sand, ranging in size from impalpable powder to about one-half the thickness of the waering surface, shall be combined in such proportions as to secure in the mineral aggregate density, or low percentage of voids, and inherent stability or resistance to displacement, producing an aggregate which, when combined with the Bitulithic Cement and laid in place and compacted, will form a street paving structure consisting of mineral aggregate of different sizes and the Bitulithic Cement which permeates the entire mass, fills the voids and unites the various articles thereof. If the crushed stone and sand do not contain enough finely divided particles or impalpable powder to produce a low percentage of voids in the aggregate, the deficiency shall be made up by the addition of any other suitable fine mineral matter.

"**Method of Laying.** The mixture and ingredients thereof shall be maintained at a temperature consistent with good workmanship. The mixture when reaching the street shall be hot enough to allow of being easily spread and raked and shall not be so hot as to injure the Bitulithic Cement.

"**Surface Finish or Seal Coat.** There shall be spread over the Bitulithic surface mixture a seal coat, using per square yard of Bitulithic pavement approximately ¼ gal of Bitulithic Cement, into which shall be incorporated approximately 25 lb of mineral aggregate not larger than ¼ in diameter. After spreading the seal coat, it shall be thoroly rolled into the Bitulithic surface mixture. On grades a coarser aggregate may be used.

"**General.** Each layer of the work shall be kept as free as possible from dirt, so that it will unite with the succeeding layer.

"The bituminous composition or cement shall in each case be free from water and shall be especially refined to remove volatile and other matter susceptible to atmospheric influences.

"Warren Brothers Co., owner of the patents used in the construction of the Bitulithic Pavement, shall file with the proper official or board which is about to receive bids for the work, a properly executed binding agreement to furnish any contractor desiring to bid for the work all the necessary Bitulithic surface material, mixed ready for use, and Bitulithic Cement, and the sand, gravel, or stone screenings for the surface finish course, in accordance with Sections Wearing Surface and Surface Finish, at a definite reasonable price per square yard. Said price shall include a license to use all of the patents required in the construction of the Bitulithic Pavement as herein specified.

"The acceptance of bids by ....
and the letting of a contract for the same shall be deemed by Warren Brothers Co. to be an acceptance of its proposal by ....
....and by the Contractor to whom such contract shall be awarded, and are all that shall be necessary to bind Warren Brothers Co. to said agreement. The filing of a bid under these specifications will be construed as an acceptance of the terms of the license agreement filed, by the Warren Brothers Co., at the price fixed in said agreement, which is on file with the proper official or board."

Bitulithic Pavement: Portland, Ore. 1917 Specifications for composition and manufacture of bituminous concrete for the wearing course.

"**Wearing Course.** Upon the rolled foundation a wearing course of the following proportions by weight shall be laid:

Aggregate passing 1½-in screen and retained on ½-in screen.........	36 to 50%
Aggregate passing ½-in screen and retained on ¼-in screen.........	12 to 20%
Aggregate passing ¼-in screen and retained on 10-mesh sieve........	8 to 12%
Aggregate passing 10-mesh sieve and retained on 200-mesh sieve.....	24 to 32%
Aggregate passing 200-mesh sieve..............................	4 to 7%
Bitulithic cement..	7.5 to 9.5%

"From 50 to 70% of the aggregate passing a 10-mesh sieve shall pass a 40-mesh sieve and from 20 to 35% of the sand shall pass an 80-mesh sieve.

"After the broken stone and sand shall have been heated in a mechanical rotary drier to a temperature of between 121 to 148° C (250 to 300° F), the whole mass shall be elevated and passed thru a rotary screen having circular openings of a maximum diameter of 1½ in and a minimum diameter of 1/10 in. The stone and sand thus separated shall pass into separate bins or compartments, from which they shall be drawn separately into a weigh box in the proportions above specified. If the proper proportion of filler be not obtained from the crushed rock, the deficiency shall be supplied by the addition of hydraulic cement or pulverized stone of an approved quality."

Bitoslag Pavement Specifications, as used in 1918, are as follows:

"Bitoslag wearing surface shall consist of a predetermined combination of properly graded crushed slag, Bitoslag Paving Cement and approved mineral dust or filler. A fundamental feature of Bitoslag construction is the scientific predetermination of the grading of the mineral constituents of the wearing surface above referred to so that the voids of said mineral aggregate shall be filled to the limit to safety, thus insuring in advance a pavement of maximum density and one thereby able to withstand the wear of traffic and action of the elements.

"**Materials.** Slag shall be a carefully selected, air-cooled basic, blast furnace product so crushed that all particles will pass a ¼-in screen.

"Mineral Dust or Filler shall be either Portland cement, pulverized limestone, or other approved finely ground absorbent mineral conforming to the following mesh composition: Passing 200-mesh sieve not less than 65%; passing 100-mesh sieve not less than 85%, total.

"**Manufacture.** Determination of Formula. The volume of voids in the mineral aggregate shall be determined and the amount of bituminous cement to be mixed with the pulverized material to form a filler product shall be established. After this, there shall be added to the mineral aggregate a sufficient amount of the filler product to fill the desired percentage of the void volume previously determined. Upon this basis the requisite quantities of the various constituents shall be computed for the batch formula which shall be adhered to by the licensee.

"Mixing. In preparing the Bitoslag paving mixture at the plant, the crushed slag, after being dried and heated to a temperature of 177° to 232° C (350° to 450° F), shall be measured or weighed into the mixer. The necessary amount of mineral dust or filler shall then be added cold and the two materials mixed mechanically until uniform. To the mineral aggregate, mixed as above described, there shall then be added the predetermined weight of melted and impregnated Bitoslag paving cement and the mixing operation further continued until the entire mass is uniform. On account of the variation, no definite percentage of bitumen can be prescribed for Bitoslag paving mixture. The bituminous aggregate when properly graded, however, shall show not less than 9.5% nor more than 11.5% of bitumen soluble in carbon disulphide. The temperature of the mixture shall be so regulated that it reaches the site of the work within the limits of 149° and 177° C (300° and 350° F).

"**Transportation and Laying.** Promptly after mixing, the Bitoslag paving mixture shall be placed in tight vehicles and transported to the location of the work and during transit it shall be covered with heavy tarpaulins for protection against the weather. On arriving at the site, the mixture shall be dumped at a point sufficiently remote from its place of final deposition to insure all portions of the load being turned over by the shovelers before placing. It shall then be promptly spread to such depth that the resulting layer shall, after compression, be not less than... inches in thickness. Compression shall be commenced as soon after spreading as the mixture has reached the proper temperature, best results being obtained when it has been allowed to cool only sufficiently to prevent adhesion to the roller. The roller shall be of the tandem pattern

weighing not less than 7 ton and the use of water for cooling purposes shall not be permitted on Bitoslag constructions. Rolling shall be promptly and continuously executed so that the proper surface and contour shall be obtained before the paving mixture has so cooled as to become set. During or subsequent to the process of rolling there shall be broomed over the surface a coating of mineral dust, and the rolling continued until cool. The finished highway may be opened to traffic as soon as rolling has been completed."

18. Construction of Asphalt Block Pavements

Composition of Blocks. Asphalt blocks usually have been made of trap rock screenings, mineral dust and asphaltic cement. Good blocks also have been made using copper conglomerate, and, for medium traffic, hard limestone has been used as a substitute for trap rock. The most satisfactory mineral dust, used as a filler, is uniformly pulverized limestone. Portland cement has been used, but it is no better than limestone and costs more. The blocks usually contain from 6.5 to 8% of bitumen.

Grading of Mineral Aggregate for Blocks. The following grading was recommended by the Spec. Com. Mat. Road Cons., Am. Soc. C. E. (17e):

" Passing 200-mesh sieve	20 to 35%
Passing 80-mesh and retained on 200-mesh sieve	7 to 15%
Passing 20-mesh and retained on 80-mesh sieve	12 to 30%
Passing ¼-in screen and retained on 20-mesh sieve	30 to 50%
Retained on ¼-in screen	0%."

Washington, D. C., 1914 Grading (23b), used in asphalt blocks having a bitumen content of 7% and a specific gravity of 2.43.

Passing 100-mesh sieve	22.9%
Passing 20-mesh sieve and retained on 100-mesh sieve	16.3%
Passing ¼-in screen and retained on 20-mesh sieve	59.0%
Retained on ¼-in screen	1.8%
	100.0%.

Shape and Size of Blocks. Well-made asphalt blocks are uniform in composition, texture and shape; have parallel faces; straight, unchipped and unrounded edges, and unbroken corners; and are not warped or otherwise deformed. The usual dimensions of the face of the block subjected to traffic are 5 by 12 in. The blocks are generally manufactured in three thicknesses, 2, 2½ and 3 in. Blocks should not vary more than ¼ in in length and ⅛ in in width and depth from the specified dimensions.

Tests of Blocks by Hemstreet (36). " Some of the more important tests applied to the blocks themselves are determining specific gravity, penetration of block, determination of percentage and character of bitumen, grading of mineral aggregate and water absorption. The specific gravity of the blocks for a known body material and grading is an indication of the lack of voids in the block, but the gravity can be increased by the admission of a percentage of larger stone, at the same time producing a poorer block. The punch test described in the New York State specifications is valuable if the average of a large number of penetrations is determined. Because the punch may strike a large piece of stone, thus giving a false reading, but scant reliance can be placed on the result of only a few tests. The absorption test is of but little use. A block that will absorb 1% of water will be so porous that visual inspection should reject it. It is difficult to completely remove the surface water in order to accurately determine absorption of a fraction of a percent.

" Rattler Test. The most useful test is made by a modified form of the Jones-Talbot rattler, usually known as the Hastings rattler.

"About a square yard of pavement is laid as a lining in a cylinder 37 in in diameter. The blocks are laid with tight joints as on the street and are held in place by clamps on the outer end of the cylinder. Fifty pounds of 2½-in cast iron cubes are placed in the cylinder and as the latter revolves at a speed of 37 rev per min, the cubes are carried up on the side of the cylinder and break over like the crest of a wave, thus producing a pounding, grinding action very similar to that produced by actual traffic. New cubes are used each time and the test is run for 10 000 revolutions. To reproduce climatic conditions the rattler is enclosed in an insulated chamber and the temperature reduced to −4° C (25° F) or lower in order to duplicate average winter temperature and raised to 32° C (90° F) or higher to duplicate summer temperature. This range of temperature of the test is of vital importance, for many asphalt pavements which would be suitable at 25° C (77° F) would fail utterly when subjected to extremes of temperature. The blocks are weighed before and after the test and results are calculated in pounds loss per square yard. The appearance of the blocks after the test is of great importance. They should not become rough or chipped during the cold test nor distorted under the hot test."

Manufacture of Blocks by Hemstreet (36). "The body material is usually crushed trap rock or copper conglomerate. Trap rock is hard, tough and gritty, does not polish under traffic and makes an ideal pavement. Trap is in general use in the eastern and southern states while the companies in the middle west and Canada use crushed copper conglomerate from which practically all the copper has been extracted. The latter material is even harder than trap rock, is tough, gritty, and enormous quantities are available in the copper regions. No matter how suitable the stone used, a poor pavement will result unless it is thoroly clean and freshly crushed. A small percentage of clay or soil is sufficient to form a film over the stone during the heating process. The clay bakes fast to the stone and the insulating coat thus formed prevents proper adhesion between the stone and the asphaltic cement.

"TRAP ROCK ranging in size from 2 to 6 in is procured from a clean quarry and, after crushing, is passed thru rolls and screens. By proper regulation of the machinery, it is possible to produce a uniform and desired grading. Generally the grading is so proportioned that, when the filler has been added, the grading of the total mineral aggregate will be such that practically all of it will pass a ¼-in round hole, about ⅓ being retained on 10-mesh, about ⅓ on 100-mesh, and about ⅓ passing 100-mesh. At least 25 to 30% should pass 100-mesh and the amount retained on 10-mesh may be as high as 40%. The properly graded stone is next heated and the best plants use a type of heater superior to and also much more expensive than the ordinary sand drier. It is 6 ft diameter, 13 ft long, is set level and contains a fixed spiral which guides the material thru at a uniform rate. The material to be heated is in a layer about 2 ft deep and the drum thus contains several tons. As a result the mass heats or cools slowly and the temperature can be regulated with great nicety. The product has a uniform temperature.

"VARIOUS KINDS OF FILLER have been tried such as ground limestone, Portland cement, ground shale, clay, silica, marl, coal, brick, etc. The most acceptable and generally used filler is ground limestone. The grinding may be accomplished by a variety of machines but a preferred type is the Hardinge Conical Tube Mill. This simple machine produces a uniform product. The fineness of the ground limestone or other filler is important and it is quite possible to grind limestone to such extreme fineness that it will be almost impossible to handle the block mixture at the press. All the limestone dust should pass 30-mesh sieve, about 75% should pass 100-mesh and 55% to 60% should pass 200-mesh sieve. A certain amount of 30 and 100-mesh limestone mixed with a harder body material makes a more malleable block than if a smaller percentage of finer limestone is used.

"THE ASPHALTIC CEMENT is a mixture of refined asphalt and flux or asphalts and fluxes used to bind the non-bituminous material. The manufacture of monolithic bituminous pavements is distinctly and decidedly different from the manufacture of asphalt block pavements and a knowledge of sheet-asphalt requirements has sometimes been a stumbling block in the attempted manufacture of asphalt blocks. In order to produce good blocks the asphaltic cement must possess the following characteristics: (1) Sufficient cementing power or adhesion and tensile strength; (2) stability, that is, not to harden or soften with age; (3) non-friable at low temperature; (4) minimum softening under the application of heat; (5) absence of mobile liquid

portions at highest street temperature. Ductility, tho of secondary importance, is necessary in monolithic pavements, for this is the property that provides for expansion and contraction due to temperature changes. In a block pavement the small size of the blocks and the frequent joints provide for this movement. With few exceptions, those cements which are high in ductility are brittle and friable at low temperature while the so-called short cements are tough and malleable when cold. The asphaltic cement must be suitable for the particular climate and kind of traffic under which it is to be used. This is accomplished by varying the kind and amount of flux used with the asphalt. A harder cement is required for use in the tropics than would be used in the climate of New York and a still softer cement is used to advantage in Canada. In order to have joints in the finished pavement iron out under light traffic, a softer cement is used than would be allowable under heavy traffic.

"On the Mixing Platform, the materials are weighed out for each batch according to the formula given to the mixer foreman. The time of mixing each batch is measured by a sand glass so that each batch is mixed for the same length of time. The various receptacles and the mixer itself are carefully and completely covered so that a minimum of dust escapes. The mixer used is a specially designed and very powerful machine consisting of two parallel shafts geared together, carrying heavy, chilled iron teeth which revolve within a chilled iron body. The mixer charge is somewhat as follows: Trap rock, 2500 lb; limestone dust, 750 to 850 lb; asphaltic cement, 820 to 360 lb; total, 3710 lb. The carefully proportioned and properly mixed material is next fed to a huge hydraulic press. The mold is opened, filled, closed, and the enormous pressure of 240 tons is applied to each block. The pressure is then removed, the mold uncovered and the block ejected and measured. Any variation is multiplied by 10 and shown on a dial. After measurement the block moves forward onto a conveyor belt and is carried under water for 150 ft and is then cooled and ready for use. Each press will produce 36 000 blocks per day."

Method of Laying. Asphalt block pavements should be laid on a strong foundation, usually of cement-concrete at least 5 or 6 in in thickness and, in cases of the heaviest traffic which this type of pavement can carry, 8 or 10 in in thickness. On cement-concrete foundations, the blocks are laid on a ½-in fresh 1 : 4 cement mortar bed. The blocks should be laid with close joints on grades as high as 6%. After being laid, the blocks should be covered with a thin layer of dry, clean, fine, sharp sand, which should be thoroly swept into the joints, and the surplus left upon the surface for at least 30 days. On grades above 6%, ⅜ or ½-in joints filled with Portland cement grout have been used. After the grout has partially set, the joints are raked out to a depth of about ½ in. On roadways subjected to heavy motor traffic, anchor blocks should be used. For description of anchor blocks, see Art. 19.

19. Specifications for Asphalt Block Pavements

N. Y. State Highway Comm. 1917 Specifications are as follows:

"**Size and Composition.** The blocks shall be 5 in in width, by 12 in in length, by 2 in in depth, and a variation of more than ¼ in in length or ⅛ in in width or depth from these dimensions will be sufficient ground for rejecting any block. The blocks shall consist of the following materials: Asphaltic cement; approved crushed trap rock or approved crushed limestone; inorganic dust.

"**The Asphaltic Cement** shall have the following characteristics:

1. It shall be free from water.
2. The various hydrocarbons composing it shall be present in a homogeneous solution.
3. It shall have a specific gravity at 25° C (77° F) of not less than 0.97.
4. The penetration shall be between 1.5 and 2.5 mm when tested for 5 sec at 25° C (77° F) with a No. 2 needle, weighted with 100 g.
5. Fifty grams of it upon being maintained at a uniform temperature of 163° C (325° F) for 5 hr in a cylindrical vessel, 5½ cm in diameter by 3½ cm high, shall not lose more than 2% in weight. The penetration at 5 sec, 25° C (77° F), No. 2 needle, 100 g weight, of this residue shall be at least 60% of the original penetration.

6. Its solubility at air temperature in chemically pure carbon disulphide for the following named materials, or materials similar thereto, shall be at least 99.5% for pure bitumen products, 96% for Bermudez products, 81% for Cuban products and 66% for Trinidad products.

7. The solubility of the bitumen at air temperature, in 76° B paraffin petroleum naphtha, distilling between 60° and 88° C (140° and 190° F), shall be between 65 and 80%.

8. The bitumen shall show between 8 and 18% fixed carbon.

9. It shall show an open flash point not less than 190° C (375° F).

10. It shall not contain more than 2% paraffin scale.

11. It shall show a toughness at 0° C (32° F) of not less than 10 cm. Toughness is determined by breaking a cylinder of the material 1¼ in in diameter by 1¼ in in height in a Page impact machine. (Am. Soc. Test. Mat., Aug. 15, 1908.) The first drop of the hammer is from a height of 5 cm and each succeeding blow is increased by 5 cm.

12. It shall have a ductility at 25° C (77° F) of not less than 8 cm, Dow mold.

"**Mineral Aggregate.** The crushed rock for coarse aggregate used in the blocks shall be crushed from clean hard rock and shall not contain any soft ingredients. It must be crushed so that every particle will pass a ¼-in screen.

"The inorganic dust, or filler, shall be produced from sound limestone, and shall be powdered to such a fineness that all of it shall pass a 30-mesh sieve and not less than 50% of it shall pass a 200-mesh sieve. Sufficient inorganic dust shall be used to give a minimum percentage of voids in the block, and provide a sufficient medium for absorbing the asphaltic cement.

"The block composition shall yield not less than 6.5 nor more than 8.5% of bitumen, when extracted with carbon disulphide.

"GRADING. The mineral aggregate of the blocks shall meet the following mesh analyses:

Passing 200-mesh sieve, at least	18%
Passing 80-mesh sieve, retained on 200-mesh sieve	12 to 18%
Passing 40-mesh sieve, retained on 80-mesh sieve	8 to 14%
Passing 20-mesh sieve, retained on 40-mesh sieve	8 to 16%
Passing 10-mesh sieve, retained on 20-mesh sieve	15 to 20%
Passing ¼-in screen	100%

"**Manufacture.** The use of dust coated screenings will be cause for rejection. The blocks shall receive a compression in the molds of not less than 200 tons.

"**Tests of Blocks.** The blocks shall have a specific gravity of not less than 2.45 for trap blocks, or not less than 2.30 for approved limestone blocks.

"After having been dried for 24 hr, at a temperature of 66° C (150° F), the blocks shall not absorb more than 0.75% of moisture when immersed in water for 7 days.

"The average penetration of a block shall not exceed ¼ in when tested for 1 min at a temperature of 38° C (100° F) with a cylinder ¼ in in diameter loaded with 147 lb.

"**Laying.** Upon the foundation shall be spread a bed of the thickness shown upon the plans, composed of 1 part Portland cement and 4 parts sand, thoroly mixed with sufficient water to make a stiff paste. This mortar bed shall be struck with a template to a true surface exactly parallel to the top of the proposed pavement surface and 2 in below it.

"The blocks shall be laid while the mortar is fresh and before it has begun to harden. All depressions and other irregularities in the surface shall be corrected by the contractor immediately. The blocks shall be laid by the pavers standing upon the blocks already laid and not upon the bed of mortar. The blocks shall be laid at right angles with the line of the street, and in such a manner that all longitudinal joints shall be broken by a lap of approximately 4 in. The blocks shall be so laid as to make the lateral joints as tight as possible, consistent with keeping a good alignment of the courses across the street. When thus laid the blocks shall be immediately covered with clean, fine sand, perfectly dry, screened thru a ⅛-in screen. This sand shall be spread over the surface and swept into the joints and be allowed to remain on the pavement not less than 30 days or until the action of the traffic on the street shall have thoroly ground the sand into all the joints.

"**Anchor Blocks and Strips.** On grades, curves or elsewhere as shown on the plans or as ordered by the engineer, blocks containing an imbedded anchor of iron or steel of an approved shape shall be furnished. Steel strips, 1½ in wide, ⅛ in thick and

from 2 to 4 ft long may be set on edge between courses as a substitute for anchor blocks. These anchor blocks or steel strips are to be laid in such courses and at such intervals as shown on plans or as directed by the engineer."

N. J. State Highway Dept. 1917 Specifications covering manufacture of blocks and anchor blocks are as follows:

"**Manufacture.** When compounding the above ingredients the trap rock and asphalt cement shall each have a temperature of not less than 121° C (250° F) nor more than 177° C (350° F). They shall be blended in an asphalt mixer of the pug mill type. The trap rock and filler shall be thoroly and uniformly mixed together before the hot asphaltic cement is added. After the asphaltic cement has been added, the mixing shall continue for at least 3 min and as much longer as is necessary to secure a homogeneous mixture in which all the particles are thoroly coated with the asphaltic cement. The above mixture must have a temperature of not less than 121° or over 163° C (250° or over 325° F) and while at this temperature shall be formed into blocks of the specified size under a pressure of not less than 6000 lb per sq in applied on the major face. After compressing they shall be cooled immediately in the manner required.

"**Anchor Blocks** shall, in addition to meeting the requirements specified hereinabove, have a strip of sheet iron 0.083 in in thickness and 1 in wide so imbedded in the block that it is firmly held in place, does not project less than 3/8 in or over 1/2 in below the surface of the face of the block, is elliptical in shape, the major axis of which is not less than 9 in or over 10 in and the minor axis, not less than 2 1/2 in or over 3 in."

20. Miscellaneous Bituminous Pavements Constructed by Mixing Methods

Sand Mixed with Asphaltic Oil or Asphalt Cement. The Mass. Highway Comm. has endeavored since 1908 to develop an efficient method of utilizing the local sand on Cape Cod in the construction of a type of bituminous pavement suitable for the traffic to which many of the highways in the southeastern section of Massachusetts are subjected. The conclusions and specifications of the Commission cover the fundamentals of this type of construction.

Mass. High. Comm. Report, 1915. "In the fall of 1908, the Commission decided to try some experiments with various bituminous materials mixed with hot sand. Eleven sections of road were constructed and a different bitumen was used on each. Two qualities of tar were used and nine different oils or asphalt products. In each case the subgrade was carefully prepared of the required width, and the mixture was spread as evenly as possible thereon and rolled with a light roller. The mixture was 4 in thick in the middle and 3 in thick on the sides. The sand and the bituminous materials were first heated, and then mixed by hand as thoroly as possible, before being spread on the road. Eight of these experimental sections practically failed within the year. Another section was never very satisfactory, and only two remained in good condition and are still in use, having been patched from time to time. The only sections that succeeded were the ones where a heavy oil with an asphalt base was used, or where this oil was used mixed with an equal quantity of asphalt. This latter section was much better than the other two. The daily traffic that has been carried successfully as shown by the traffic census taken in 1910, 1912 and 1915 is about as follows: Sandwich Road: 8 heavy teams, 23 light teams and 502 automobiles; Plymouth Road: 3 heavy teams, 8 light teams, 257 automobiles.

"The Commission has constructed over 23 miles of mixed sand and oil asphalt roads since the experiments made seven years ago in 1908. It has also built over 1 1/2 miles of sand mixed with tar. The roads are built over a carefully prepared and hardened base, about 4 in thick in the middle and 3 in on the sides, 18 ft in width, with 21 ft on the curves.

"Various asphalts have been used, both residuum and natural, and on this mixed work an oil asphalt is now used that tests 80 penetration on a Dow penetrometer. The quantity of oil asphalt that is used has to be varied a little according to the variations in the quantity of voids in the sand, 18 to 21 gal being used to 1 cu yd of sand.

"New mixing machines have been made, and their use insures a much more even mixture of the sand and oil. Several sand heaters have been designed and have been used with good results. In these the sand is kept in motion all the time it is being heated, insuring a uniform heating of the sand. Better results have been secured by using a road scraper and keeping the mixture constantly shaped while it is being rolled. As stated above a seal coat of a lighter oil improves the road surface and prevents it from having occasional pot-holes, and decreases the cost of future maintenance.

"The cost of these sand and oil asphalt roads has varied from 40 to 61 cents per sq yd, the average cost being 52 cents.

"There is no class of road built that will go to pieces any quicker than roads of the above character, if they are not constantly maintained. A pot-hole in wet weather will soon become as big as a bushel basket, and with many holes of this kind the road is not only very quickly destroyed by the traffic but it becomes impassable. Thousands of dollars are lost every year because this maintenance is neglected, the holes not being filled.

"The average cost of maintenance per year on these mixed roads that have been in use 5 years has been 1.6 cents per sq yd per year; on roads that have been in use 3 years the yearly cost of maintenance has been 0.75 cents per sq yd. If these roads require a seal coat every 4 or 5 years, as seems probably, the average yearly cost of maintenance will be about 2½ cents per sq yd per year."

The Mass. Highway Comm. Specifications (30b), in part, are as follows:

"METHOD OF MIXING. The sand and oil shall be mixed by hand or in a mechanical mixer. If by hand, the mixing shall be done on platforms with rakes and hoes, or by turning with shovels. The platforms shall be made of 2-in planks, and shall be about 8 ft wide by 16 ft long, but for convenience in handling may be made in 2 sections. If a mechanical mixer is used, it shall have a suitable hot attachment, so arranged that the materials will not be burned during the mixing.

"The oil or oil asphalt used for mixing shall be as ordered, but in no case shall oil having a viscosity of less than 500 sec, Lawrence Viscosimeter at 100° C (212° F) or oil asphalt having a penetration of less than 60, Dow penetrometer at 25° C (77° F) be used. The amount of oil used shall be as ordered, but in no case shall less than 15 gal or more than 20 gal be used per cu yd of loose sand. The oil shall be heated to a temperature of from 121° to 191° C (250° to 375° F), depending on the nature of the oil or oil asphalt used.

"The sand shall be clean, sharp, fairly coarse and well graded, and shall contain no adventitious material of any kind. It shall contain no stones more than ½ in in their longest dimensions, or over 52% passing a 50-mesh sieve. The sand when mixed with the oil shall be dry and so heated, that a uniform mixture will be secured. Care must be exercised not to overheat the sand so as to burn the oil.

"METHOD OF LAYING. When the mixing is completed to the satisfaction of the engineer, it shall be transported immediately to and spread on the road. It shall not be dumped directly on the subgrade, but upon dumping boards or iron plates; the dumping boards or plates to be of sufficient size to retain all of the mixture when dumped. The mixed material after it is deposited in place shall be shaped with rakes and immediately rolled with a horse roller weighing about 1 ton. The surface shall be shaped with a road machine or suitable scraper and afterwards rolled with a tandem steam roller. The length of time elapsing before rolling with the steam roller shall be as ordered by the engineer. Any depressions appearing in the surfacing shall be filled with mixed material satisfactory to the engineer. If such depressions are found after the sand and oil have hardened so the new material will not bond readily with the old, a sufficient amount of the old material shall be dug out to allow the placing of not less than 2 in of the new mixture, which shall be thoroly rolled. Any slight unevenness of the surface shall be remedied by scraping with a road machine or suitable scraper and the surface again rolled.

"SEAL COAT. After the sand and oil mixture has been shaped and rolled to the satisfaction of the engineer, a seal coat of asphaltic oil shall be distributed on the surface in 2 applications of ¼ of a gal per sq yd. Each application of oil shall be covered with a thin layer of sand spread evenly over the surface and rolled with a steam roller, additional sand being added as needed to absorb any flushing to the surface. The asphaltic oil used for the seal coat shall be of a grade satisfactory to

the engineer, but in no case shall oil having a viscosity of less than 250 sec, or more than 600 sec, Lawrence viscosimeter at 100° C (213° F) be used. The oil shall be heated in tank cars or otherwise and shall be transported to the work in suitable distributor carts or trucks. It shall have a temperature of approximately 121° C (250° F) when applied. The oil shall be applied by a pressure distributor which will spread it evenly over the surface, leaving no spots or streaks uncovered, and no overlapping will be allowed.

Clay or Loam Mixed with Asphalt Cement. In 1912 a mixture of pulverized clay and asphalt cement was laid in Iola, Kan. Since 1912 several sections of this type of bituminous pavement have been laid thruout the United States.

Method of Construction (51b). "In constructing this pavement, a specially designed machine thoroly pulverizes the soil which is fed into it, which may be that excavated from the road in grading, at the same time evaporating the moisture contained therein and heating all material to the degree necessary for uniform and easy mixing. There are two drums, the inner of which has blades on the outer circumference. The outer drum acts as a heater. The inner revolves at a rate of about 600 rev per min, and the blades, which are arranged normal to a helix so that the material is worked toward one end, throws the material against the outer drum. It is raised by flights on the inner surface of the outer drum, which revolves slowly, and as it falls back it is again caught by the blades, this process being repeated until all the earth is pulverized completely and comes out as flour. A screen prevents unpulverized particles from coming out. Any sand particles come out clean and bright. The bituminous binder is then mixed with the pulverized, dried and heated material in a regular asphalt mixer. The product as it comes out resembles pulverized rock asphalt more than it does sheet-asphalt, tho it can be handled in the same way as the latter. It is hauled to the road, spread, and rolled when sufficiently cool. The material which has been used as mineral aggregate in Iola is a clayey sub-soil excavated from the street to be paved. This material, which is commonly known as gumbe soil in the middle west, is considered the most refractory soil or clay to work up into paving, yet it was readily pulverized and mixed with the asphaltic cement."

Report by Dow (51b). "The National pavement is composed of asphalt cement mixed with pulverized clay or loam which may contain more or less sand or fine stone. Owing to the strong affinity for bituminous materials like asphalt cement possessed by the colloidal silica and silicates contained in clay and clayey soils, and also to the fine state of division of the pulverized clay, a very soft asphalt cement may be used in the mixture without danger of producing a pavement too soft for traffic. In this respect it has a distinct advantage over other types of bituminous pavements, for it is a well known fact that the softer the asphalt cement used the longer the life of the pavement, provided it is not so soft as to roll under the traffic. As to the wearing qualities of this paving material no one can say from a practical experience, but, judging from its characteristics, it is hard to appreciate how it can be worn away. The wearing can not take place in a manner similar to the other types of bituminous pavements constructed with sand and coarse mineral aggregate. In these materials, the coarse mineral matter slowly pulverizes under traffic and grinds away, but in the case of the National pavement the clay is already pulverized to as fine a condition as possible and there can not be any further grinding of the particles. One great advantage which this paving material possesses over that of other bituminous pavements is that it is made of finely pulverized clay with little or no gritty particles contained in it. It will not have the same wearing effect on rubber-tired vehicles which are now so much in use on our public highways."

In a later report (1917) Dow states that, "as the National pavement is composed of the finest divided mineral particles which present a large surface area to be covered with bitumen, its asphalt contents is much greater than that of any other type of bituminous pavement, thus making it a more malleable material. This great malleability will prevent the formation of cracks and depressions in the pavement when it is subjected to traffic, and will tend to keep the surface smooth and uniform and free from ruts."

Specifications for National Pavement are, in part, as follows: "Upon the foundation prepared and laid as elsewhere herein specified shall be laid the pavement proper.

This shall consist of a bituminized earth wearing surface ... inches in thickness composed of: Pulverized clay, loam or earth, 80 to 85%; asphalt cement, 15 to 20%.

"ASPHALT CEMENT. It shall have a penetration at 25° C (77° F) of from 80 to 150 depending on the fineness of the pulverized earth, the traffic, and the local climatic conditions.

"PULVERIZED EARTH, CLAY OR LOAM. This shall be an earthy material complying with the following requirements, the tests being made on the dried material.

1. Upon sifting it shall have the following mesh composition:

Passing 200-mesh sieve	50 to 100%
Passing 50-mesh sieve, and retained on 200-mesh sieve	0 to 30%
Passing 20-mesh sieve, and retained on 50-mesh sieve	0 to 20%

2. When the earth, clay or loam is worked into a stiff paste and molded into a standard cement briquette it shall, after drying, show a tensile strength of not less than 50 lb per sq in.

3. It must be soluble in dilute hydrochloride acid (1.2) to the extent of not less than 5 nor over 15%.

4. The pulverized earth must not contain more than 5% of carbonates.

5. On igniting at a red heat, it shall lose between 3 and 12%.

"WEARING SURFACE. The earth must be heated and pulverized by passing thru a revolving drum containing a disintegrator of approved type. The pulverized earth when used must be at a temperature between 93° and 149° C (200° and 300° F). The asphalt cement when used must be at a temperature between 121° and 149° C (250° and 300° F). The pulverized earth and asphalt cement shall be brought together and mixed for at least 1 min in a suitable appliance until a homogeneous mixture is produced in which all the particles are thoroly coated with asphalt cement.

"LAYING. The surface mixture prepared in the manner above described shall be brought to the work in wagons and upon reaching the street, shall have a temperature between 93° and 135° C (200° and 275° F). The temperature of the surface mixture within these limits shall be regulated according to the temperature of the atmosphere and the working of the mixture and the character of the materials employed. On reaching the street it shall at once be dumped on a spot outside of the space on which it is to be spread. It shall then be deposited roughly in place by means of shovels, after which it shall be uniformly spread in place by means of hot iron rakes in such a manner that after having received its final compression by rolling the finished pavement shall conform to the established grade. The thickness of the finished surface mixture shall average 2 in. Not more than 10% variation from the average thickness specified will be permitted in any one spot. After raking, the surface mixture shall be compressed by rolling or tamping. After it has received its first compression and has cooled sufficiently, the surface shall then be thoroly compressed by a steam roller weighing not less than 200 lb per in width of tread, the rolling being carried on continuously at the rate of not more than 200 sq yd per hr per roller until a compression is obtained which is satisfactory to the engineer."

Wood Fibers Mixed with Bituminous Cement. In 1911 an experimental section of bituminous pavement of this type, known as Fibred-Asphalt, was constructed in St. Albans, W. Va. under the direction of the patentee, Geo. H. Henderson. Since 1911, sections have been constructed in several states, including Delaware, New York, and Tennessee.

Method of Manufacture and Construction (27a). "This pavement consists of the fibers of hard wood, impregnated with a preservative compound and bound with a bituminous material. The fiber used is the toughest sinew of hard wood remaining after the deteriorable, evaporable sap, essences and softer portions of the wood have been extracted and removed. It is obtained as a by-product of the manufacture of tannin and other essences. In preparing the material for pavement purposes, the fibers are removed from the extract vats by endless belts and conveyed to vacuum driers. After being dried they are screened, the largest chip used being that passing a 3-mesh sieve. Four different sized sieves are used, the various sizes of chips being afterwards mechanically mixed in the predetermined proportions, from the larger sizes down to wood flour. The dry graded chips are next conveyed to a mixer, where the impregnating preservative is added, and are then coated with molten asphalt.

The mixture is next discharged into molds 4½ ft by 6½ ft and compressed into 4 ft by 6 ft blocks ready for shipment.

"In laying the pavement the prepared material is shipped in blocks to the site of the work. The blocks are then chopped up into 3 or 4 pieces and placed in a special portable reheating machine, from which the material is discharged hot onto the prepared road-bed, and mechanically spread by an attachment to the machine to a uniform depth of 4 in uncompressed. The hot material is then tamped by hand by large wooden tamps, first dipped in water to avoid picking up the sticky material. The tamping operation is followed by a series of steam rollings until the material is compressed to a compact, homogeneous mass 2 in thick, this constituting the wearing surface of the road. The cost of the reheating machine complete is $2500, and it is stated that the entire force required for its operation, including shaping and tamping of the mechanically spread material, consists of 1 expert, 1 foreman, 1 engineer and 12 laborers. In addition there will be the steam roller operators. The cost of the prepared material f.o.b. cars is stated to be about 42 cents per sq yd of finished road, and it is further stated that 2-in pavement can be constructed at a cost of about 60 cents per sq yd, this including royalties, labor and all charges."

21. Construction Cost Data

The cost of bituminous concrete pavements varies with the kind and quantity of bituminous material used, the character of the aggregate and the method of construction employed. Using an aggregate of stone varying from ⅛ to 1¼ in in longest dimensions, mixed with 5 to 8% of bitumen, and a seal coat of ¾ gal per sq yd, the cost of a 2-in wearing course should be 30 to 50 cents per sq yd in excess of water-bound broken stone roads. The cost of pavements of Classes B and C usually varies from $1 to $2.50 per sq yd, including foundations and light grading. Asphalt block pavements on 5 or 6-in cement-concrete foundation vary in cost from $2 to $3 per sq yd.

Records of Cost Data for Class B Pavements by White (73a). In describing the construction of bituminous concrete pavements, South Park, Chicago, the following details of recording costs of operation of a Link-Belt Portable Asphalt Plant and the laying of the daily output, which frequently amounted to 1250 sq yd of 2-in surface, are cited.

"The surface foreman's report on work order No. 2201 of the same date records: Date; work number; location of work; thickness of asphaltic concrete laid; square yards of each thickness; number and duties of each man employed; number of hours and rate per hour of each man; total batches received from each asphalt plant; number gallons for squeegee; number cubic yards and kind of sand; number of pounds of coal.

"The surface foreman's labor report on work order No. 2201 of the same date also records:

Number of men	How Occupied	Rate per Hour in Cents	Hours Worked
1	Top foreman	40.0	9.0
4	Laborers raking	38.0	42.0
1	Laborer tamping back	38.0	10.5
2	Laborers tamping	32.0	21.0
4	Laborers spreading	27.0	42.0
1	Laborer dumping carts	27.0	11.5
1	Laborer painting joints	27.0	11.5
1	Laborer spreading sand	25.0	10.0
1	Timekeeper	27.5	2.0
2	Ten-ton rollers	55.5	21.5
1	General foreman	55.6	1.0

"The daily report of the asphalt plant foreman records: Date; work number; location of work; total batches delivered by each asphalt plant; hours delay and cause; number and duties of each man employed; number of hours and rate per hour of each man; amount of asphalt used; amount and kinds of stone used; amount and kinds of sand used; amount of coal used; amount of gasoline used.

"In order to illustrate the data as to number, rate, and hours of men employed in the asphalt plant crews, the asphalt plant foreman's report on work order No. 2201 of July 1, 1912, is quoted as follows:

Number of Men	How Occupied	Rate per Hour in Cents	Hours Worked
1	General construction foreman	55.6	1
1	Asphalt plant foreman	33.8	9
1	Traction engineer	55.5	12
2	Firemen	29.7	18
4	Asphalt cutters	25.0	36
4	Tankmen	25.0	36
6	Feeders	25.0	54
4	Mixers	25.0	36
2	Coal men	25.0	18
6	Men cleaning up	21.8	54
4	Linemen	25.0	36
1	Oiler, machine tender	30.0	12
4	Carts hauling hot ashpalt	50.0	24
4	Carts moving material	50.0	12
1	Team cleaning up	68.7	9
1	Timekeeper	33.8	2
2	Timekeepers	27.1	4
2	Watchmen	25.0	18
1	Water boy	12.5	8

Cost Data Relative to Class B Bituminous Gravel Concrete Pavement built in 1916 on the Alexandria-Accotink Road, Fairfax County, Va., under the direction of the U. S. O. P. R. (67d). For details of construction, see Art. 14.

Unit Prices of Labor, Teams and Trucks: Foremen, rollermen and skilled laborers, $4 per 8-hr day; common laborers, $1.60 to $2.00 per day; teams, $4.50 per day; trucks, $1 per hr.

Labor Costs in cents per sq yd: Hauling asphalt, 1.424; mixing, 15.156; hauling mix, 6.64; setting headers, 1.421; spreading mix, 3.627; rolling, 0.765; sealing, 1.315; hauling pea gravel, 0.777.

Costs of Materials: Gravel, 10 cents per cu yd and 0.91 cents per sq yd of 2 in wearing course; asphalt, $15 per ton and 14.59 cents per sq yd; limestone dust, $6 per ton and 1.53 cents per sq yd; pea gravel for seal coat, $1.50 per ton and 1.42 cents per sq yd.

Total Cost: Labor per sq yd, 31.13 cents; material for bituminous concrete per sq yd, 18.45 cents; total cost of 2-in bituminous gravel concrete wearing course, 49.58 cents per sq yd.

Cost Data Relative to Topeka and Bitulithic Pavements. In Tables IV and V are given, for several localities in the United States, 1916 prices of Topeka and Bitulithic pavements on cement-concrete foundations.

Cost Data Details of Topeka Pavement in Holland, Mich. (51a). "The paving proper consisted of 6 in of Portland cement-concrete and 2 in of asphaltic concrete; the latter being the combination known as Topeka specification. The material for the bituminous wearing surface cost as follows: Pioneer asphalt, 10.1 cents per gal; stone, ½ in, $1.20 f.o.b. on the dock, average haul, 1 mile; sand, 90 cents per yd. Teams cost $4 per day; labor, $2 per day on a 9-hr basis; and an inspector and foreman combined, $5 per day.

Table IV.—Cost of Topeka Pavements in 1916 in Several Cities
From *Engineering and Contracting*, April 4, 1917

City	Square Yards	Price* per Sq Yd	Guarantee Years	Wearing Course Thickness Inches	Concrete Foundation	
					Thickness Inches	Proportions
Albany, N. Y.	13 393	$1.71†	5	2½	6	1:3 :6
Harrisburg, Pa.	10 361	1.33†	5	2	4	1:3 :5
Newark, Ohio	13 248	1.58	5	2	4	1:6
South Bend, Ind.	37 444	1.48†	5	2	5	1:3 :6
Chicago Heights, Ill.	57 000	1.00	5	2	6	1:3 :6
Fond du Lac, Wis.	22 375	1.53	5	2	5	1:3 :5
St. Paul, Minn.	95 350	1.54	..	2	5	1:3 :5
Sioux Falls, S. Dak.	84 243	1.59†	5	2	6	1:2½:5
Manhattan, Kan.	41 000	1.22†	5	2	5	1:3 :5
Chattanooga, Tenn.	32 520	1.40†	5	2	5	1:3 :6
Hillsboro, Tex.	13 000	1.60†	5	2	5	1:3 :5
Vallejo, Cal.	40 000	1.08†	..	1	4	1:2½:5

*Price covers pavement, foundation, and shaping subgrade.
†Does not include shaping subgrade.

"Sixteen men were used in the concrete gang and 13 men in the asphalt gang, the latter including the roller man and engine tender. Two Rapid mixers were used, the same machines being used for both Portland cement-concrete and bituminous concrete. The paving machinery having been purchased by the street fund, 6 cents per sq yd was paid into this fund for the use of the machinery, or a total of $967.26. One hundred dollars was also paid into the same fund for the use of the city roller.

"The 6-in concrete base was put down for 41.2 cents per sq yd and the 2-in asphaltic concrete top for 54.2 cents per sq yd, making a total cost of pavement of 95.4 cents per yd."

Table V.—Cost of Bitulithic Pavements in 1916 in Several Cities
From *Engineering and Contracting*, April 4, 1917

City	Square Yards	Price* per Sq Yd	Guarantee, Years	Wearing Course Thickness, Inches	Concrete Foundation	
					Thickness, Inches	Proportions
Cambridge, Mass.	10 310	$2.75	5	2	5	1:2½:5
Providence, R. I.	20 552	2.10	5	2	6	1:3 :6
Elmira, N. Y.	10 643	2.25	5	2	5	1:2½:5
Harrison, N. J.	18 512	2.20	5	2	6	1:3 :6
Cincinnati, Ohio	1 088	2.40	5	..	..	1:3 :6
Battle Creek, Mich.	63 943	1.28	..	2	5	1:6
Muscatine, Iowa	25 615	1.83	5	2	5	1:6
Sioux Falls, N. Dak.	42 734	2.10†	5	2	6	1:2½:5
Greensboro, N. C.	8 516	1.50	..	2	4	1:3 :6
Austin, Tex.	60 143	2.00†	..	2	5	1:5
Butte, Mont.	22 586	2.55	5	2	4	1:3 :5
Denver, Colo.	25 000	2.00	5	3	5	1:3 :5

*Price covers pavement, foundation, and shaping subgrade.
†Does not include shaping subgrade.

Table VI.—Cost of Asphalt Block Pavements in 1914 in Several Cities
From *Engineering and Contracting*, April 7, 1915

City	Square Yards	Price* per Sq Yd	Guarantee, Years	Concrete Foundation	
				Thickness, Inches	Proportions
Holyoke, Mass.	5 567	$2.38	..	4	1:2½:5
Jamestown, N. Y.	9 423	2.35†	..	5	1:2½:5
Niagara Falls, N. Y.	34 165	2.62	5	6	1:3 :6
Toledo, Ohio.	7 794	2.00†	5	5	1:3½:6
Windsor, Ont.	36 086	2.75†	5	6	1:2 :4
Regina, Sask.	28 525	3.00	15	5	1:6

*Price covers pavement, foundation, and shaping subgrade.
†Does not include shaping subgrade.

Cost Data Details of Bitulithic Pavement in Portland, Ore. (52). "The costs of materials and labor, both at the paving plant and on the street, are based upon daily cost records kept by the Bureau of Standards of the City of Portland in 1915 and 1916 involving the laying of 24 843 sq yd of 2-in Bitulithic wearing surface.

	Per Sq Yd
MATERIALS	
Asphalt cement at $10.50 per ton	$0.128
Sand at $0.45 per cu yd	0.018
Rock screenings at $0.93 per cu yd	0.032
Portland cement	0.000
Crushed rock at $0.93 per cu yd	0.038
	$0.216
MIXING PLANT COSTS.	
Labor	$0.0340
Fuel oil, $1.10 per bbl	0.0190
Lubricating oil	0.0007
Power	0.0030
	$0.0567
HAUL, average of 3 miles	$0.0610
STREET COSTS	
Labor	$0.0430
Coal for roller, $6 per ton	0.0005
Coal oil at $0.10 per gal	0.0004
	$0.0439
TOTAL FOR MATERIAL AND LABOR	$0.3800
OVERHEAD	
Maintenance and repairs to plant and equipment	$0.020
Depreciation and obsolescence of plant and equipment, 20%	0.046
Interest on plant and equipment at 6%	0.014
Supervision and office expense	0.065
Taxes and use of plant site	0.037
Insurance	0.003
Total superintendence and overhead	$0.185
TOTAL FOR PAVEMENT	$0.565

NOTES: The cost allowance of $0.02 per sq yd for maintenance and repairs to plant is based upon the actual guarantee that manufacturers of certain paving plants are willing to make on their plants for a moderate amount of paving.

"The cost factor for depreciation and obsolescence is based upon plant and equipment valued at $15 000 and upon a yearly output of 65 000 sq yd, which was the output of the contractors' plants in 1915. The factor of 20% for depreciation, which is based on the allowance made for depreciation on the District of Columbia paving plant, is liberal, for the Warren Brothers Co. use a factor of 10% depreciation on their plants.

"The cost of supervision and office expense is based upon the following force: A superintendent at $2400 per year, one bookkeeper at $1200 per year, and a stenographer at $600. This force is considered as working thruout the entire year and devoting all its attention to paving, tho in actual practice a force of this kind handles many other contract items than paving in a year's work.

"The cost item of taxes and use of plant site is based upon the payment of a rental of $200 per month for a plant site. This is a far higher rate than probably any of the plants in Portland pay."

MAINTENANCE

22. Causes of Failure

The percentage of failures of bituminous concrete pavements is much smaller than in the case of bituminous macadam pavements. Failures may be considered from the standpoint of inadequate drainage and foundations, the materials employed, and methods of construction adopted. Many failures have occurred because the type of pavement used was not suitable for the traffic or other local conditions. From an economic standpoint, numerous failures are due to inefficient maintenance.

Failures Due to Frost Action on Ashokan, N. Y., Highways (20). "At a number of culverts which had heaved with the frost, a greater thickness than the theoretical 2-in wearing course was necessary as it was considered advisable not to decrease the thickness of the bottom course of crushed stone over the culvert, but to give the road a gentle slope each side of the culvert. Numerous bumps or warts on the road which were removed proved to be caused by the working up of boulders by the frost. The boulders varied in size from 2 to 200 cu ft. These at the time of construction had either been below the sub-grade or had been leveled off to that grade, it being thought better to keep them in place rather than remove them with consequent soft places in the foundation. This work was accomplished with the City's forces by barring and wedging or by light charges of powder."

Materials. Poor and unsuitable materials have been accountable for certain failures. In some cases an apparent cause of failure has been an excess of flux or of the volatile constituents in asphalt cements. Pavements constructed with such materials are frequently wavy, due to the movement of the surface under heavy traffic. The use of bituminous cements having too low penetration has resulted in the cracking or general disintegration of the pavement. Many causes of failure would be eliminated if engineers would devote more time to a consideration of the physical and chemical properties of the materials which they employ. If a bituminous material laboratory is not connected with the department, it should be neither expensive nor difficult to secure certified analyses made by reputable chemical engineers.

Either too large broken stone or stone of too uniform size may cause a failure. Especially is this the case with very hard and tough broken stone. The rocking of the stone causes the formation of fine cracks which eventually lead to disintegration. Poor combinations of sizes of broken stone and sand have resulted in segregation during mixing, transportation or spreading, resulting in a pavement of varying density and stability.

Construction. Many cases are reported where materials have been overheated due to the belief that all materials may be and even should be heated to the same temperature before using and that it is impossible to

injure bituminous materials by heating to high temperatures. Overheating of the mineral aggregate has caused burning of the bituminous material in some instances or the formation of a thin film of bituminous material over the broken stone which is not of sufficient amount to bind the adjacent particles together. The use of a wet aggregate will result in a poor mix with consequent unsatisfactory results. In many instances the seal coat has not been applied uniformly. The result is either uneconomical, due to the necessity of a second application before 75% of the surface requires retreatment, or the disintegration of the pavement whenever bare spots occur in pavements where a coarse aggregate was used and where there is considerable horse-drawn vehicle traffic. Some failures have been caused by using unheated stone with bituminous cements which will not adhere satisfactorily or which mix only with great difficulty under such conditions.

Causes of Waviness by Smith (60a). "Whatever type of construction is decided upon, it must always be borne in mind that a bituminous wearing surface is flexible and will only give good service when it is properly supported by an adequate foundation. Soft spots or weak places in the foundation will cause a settlement of the overlying wearing surface which will result in rapid deterioration. Water will collect in such low spots and rapidly destroy the bond between the bituminous binder and the mineral aggregate. The wheels of each vehicle passing over such depressions will strike a heavy blow as they drop into them and cause displacement of the wearing surface, resulting in the formation of a ridge which still further adds to the vibration of the springs and causes successive blows to be dealt to the pavement until the spring vibration becomes normal again. This, of course, results in the formation of waves. In most heavy commercial vehicles the springs are comparatively short and stiff. The vibrations are, therefore, quick and tend to strike very heavy blows, resulting in wave formation at right angles to the line of traffic having their crests from 3 to 4 ft apart. This is plainly noticeable on roads having a bituminous wearing surface and it is still more evident on water-bound macadam roads. The poorer and less rigid the foundation the more pronounced the waves. This is quite distinct from the shearing or shoving action exerted by vehicles rounding curves at a moderately high rate of speed. The motor-bus is perhaps more directly responsible for this type of wave formation than any other modern type of vehicle. In England, more especially in the neighborhood of London and other large cities, it is easy to pick out those roads which carry motor-bus traffic, as they invariably show the kind of wave formation above described. On water-bound macadam roads it is no uncommon thing to find considerable stretches in which the difference in level between the wave crests and troughs amounts to 4 in and over. This wave formation is noticeable in rock and sheet-asphalt pavements laid on 9 in of concrete as well as on country roads covered with sheet-asphalt, tarred slag, bituminous concrete or bituminous macadam. Generally speaking, the wave formation in sheet or rock asphalt pavements laid on concrete foundations, while noticeable, is not excessive, whereas in bituminous surfaces on inferior macadam foundations it is one of the primary causes of disintegration. The consistency of the bituminous binder used in these English roads is on the average somewhat harder than that used in the United States and there are no long hot periods to soften them up such as are frequent here. In their very moist climate it has been found that a harder bitumen adheres more tenaciously to the mineral aggregate and is less affected by water action. It is fair to assume, therefore, that their road surfaces are at least no more plastic than ours and personal examination showed that in the majority of them the bonding qualities of the bitumen had not been weakened by water action and that the grading of the mineral aggregate was normal. It is believed that much of this could be avoided by having longer and more flexible springs on vehicles of this type, thus greatly lessening the road shock.

"Slow moving, heavily loaded vehicles are much more prone to cause displacement and wave formation than are the lighter type of vehicles moving at a speed of from 15 to 25 miles per hr. This was clearly shown by a 60-ft street in one of our eastern cities, which was paved with a bituminous concrete mixture containing more stone than the average Topeka mixture. The foundation was 5 in of concrete and the average grade about 3%. A trolley line in the center of the street sharply divided

the moving traffic. The traffic up-hill was composed largely of slow-moving, loaded, 3 to 4-ton horse-drawn vehicles and a few motor trucks, whereas on the down grade it was confined to light delivery wagons and empty trucks, but the number of vehicles on each side was about equal. The pavement on the up-hill side very soon developed wave formation to such an extent as to require a large amount of resurfacing, whereas that on the down-hill side gave satisfactory service for a long period with practically no wave formation. Both sides were laid with the same mixture and at the same time. The concrete in many places was defective and at these points the wave formation was most marked."

Theory of Cause of Waves in Bituminous Pavements. Hempelman (85) states that in St. Louis there has been recorded on the surface of bituminous pavements a temperature of 142° F and in less than 6 months a temperature of 4° below zero. It was thought that there might be a sufficient difference in temperature between successive imaginary layers, meaning at different depths from the surface in contact with the wheels of the passing vehicle, as to result in a material change in the consistency of the asphaltic or tar binding cement for these various depths under the climatic conditions such as obtain in Missouri and other states of the central Mississippi valley. It is not uncommon in this section to experience a dry, hot spell of from 5 to 8 weeks, during which period the atmospheric temperature may not fall below 80°. In other words, there is not a marked cooling of the atmosphere with sundown, and, hence, the pavements do not cool to the same extent for their entire depth, as in other localities, all of which means the pavement tends to remain soft or plastic, due to the softening or change in consistency of the bituminous cement.

The temperatures recorded in Table VII were obtained by drilling holes into the pavement, inserting thermometers to the depths indicated, and packing the spaces about the thermometers with a mixture of sand and a heavy flux oil.

Table VII.—Temperatures at Different Depths in a Bitulithic Pavement on Sept. 12, 1912

Time	Air: °F	1 In: °F	1½ In: °F	2 In: °F	2½ In: °F
9.30 A.M.	90.0	94.0	91.5	90.0	88.0
10.00 A.M.	93.0	97.5	94.2	91.8	89.5
10.30 A.M.	95.4	101.5	97.5	94.8	91.8
11.00 A.M.	99.0	104.0	99.2	96.0	93.5
11.30 A.M.	102.0	109.0	104.5	100.5	97.5
12.00 N.	104.3	111.2	106.8	103.0	100.2
12.30 P.M.	104.0	113.0	108.5	105.0	102.2
1.00 P.M.	103.0	113.8	110.0	107.0	104.2
1.30 P.M.	104.0	114.5	111.0	108.0	106.0
2.00 P.M.	104.0	114.0	111.0	109.0	107.0
2.30 P.M.	103.0	113.2	110.6	109.0	107.3
3.00 P.M.	100.0	109.2	107.6	107.5	106.5
3.30 P.M.	98.5	106.0	105.0	105.5	105.0
4.00 P.M.	96.0	103.5	102.8	104.0	103.5
4.45 P.M.	93.0	101.0	100.8	102.3	102.0

CONCLUSION. Hempelman concludes that with the difference in temperature for the different depths, as indicated, it would seem that the change in consistency of the asphaltic cement for these different depths might easily permit the shifting of the wearing surface material where the bituminous cement used was of a susceptible nature, that is, a material which changes decidedly in consistency for slight changes in temperature.

Causes of Failure of Bituminous Gravel Concrete Pavements by Howard (89). The practical objection to the use of gravel, as found in a bank or pit, is the lack of uniformity as stored by nature. Where poorly graded sizes have been used, voids or pockets are formed; even tho some sand, etc, is mixed with the gravel. Rain and the elements of weather, the worst enemies of roads, cause water to enter these voids and disintegrate the roads, aided by freezing and expanding. The weather, and especially

contraction in cold weather, causes many minute cracks; and traffic disengages the gravel and ravels the road surface. Other failures occur when too large sizes of gravel are used, where stones are of greater or almost as great diameter as the thickness of the wearing surface. If water-soluble cementitious clay is present on the gravel, then it remains as a film or layer, coating each particle of gravel, and thus prevents the bituminous cement from coming in contact with and adhering to the gravel. If the surface of a gravel is too smooth and polished, bituminous cements sometimes fail to adhere.

"The bituminous gravel concrete roads or pavements which have succeeded in a few parts of the United States are those containing very hard and durable gravel, having surfaces to which bitumen can adhere, and of such expressly graded sizes that such gravel can be combined with some sand and suitable finer filler to make a dense mineral mass with a low percent of voids."

23. Methods of Maintenance

Repairs to Seal Coats. Due to ordinary wear under traffic, the seal coat of a bituminous concrete pavement usually requires repairing independent of repairs to the bituminous concrete of the wearing course. Wear of seal coats is generally characterized by the development of small areas of surface devoid of a thin coat of bituminous cement. Similar bare spots will be found early in the life of some pavements due to lack of uniformity in the distribution of the bituminous cement for the seal coat during the construction of the pavement. Such areas may be satisfactorily repaired by the following method: Thoroly clean the exposed surface of the wearing course of bituminous concrete, when dry, by first brushing with stiff brooms and then removing the fine dust by brushing with fine fiber brooms, such as those made from bass wood; apply with a broom or brush the hot bituminous cement, using from 1/8 to 1/2 gal per sq yd, dependent upon the porosity of the bituminous concrete surface and the kind of bituminous cement used; for close mosaic surfaces, cover the bituminous cement with a thin dressing of Portland cement, and for porous surfaces use a covering of grit, preferably stone chips free from dust.

Long narrow strips of exposed surface may be repaired by using a conical pouring can, such as is used for filling joints of block pavements with bituminous cement. By brushing or squeegeeing the stream of bituminous cement thus distributed, a satisfactory coating of bituminous cement may be secured. For large areas requiring renewal of the seal coat, pouring pots or hand-drawn distributors from which the bituminous cement flows in the form of a sheet, or hand-drawn pressure distributors may be efficiently used. Wide squeegees or brushes should be used immediately following the application of the bituminous cement to insure uniform distribution. For large areas it is usually better to use stone chips rather than Portland cement for a dressing.

The bituminous cement used should be of the same general type as employed in construction. If tar cement was employed, a tar, which may be applied hot or cold, may be used with good results. If asphalt cement was used for the original seal coat, a cut-back asphalt or an asphalt cement may be used. The penetration of the asphalt cement under a load of 100 g for 5 sec at 25° C (77° F) should be between 90 and 120 for oil asphalts and as high as 140 to 170 for cements similar to Bermudez asphalt cement. It will not be difficult to secure a satisfactory bond between an asphalt cement and the surface of the wearing course provided the surface is dry and the work is done when the air temperature is not less than about 20° C (68°F).

Renewal of Seal Coats. The details of the methods outlined for repair-

ing seal coats apply with equal force to the renewal of seal coats. On sections over 2000 ft in length, a different plant equipment should be used. Altho by using pouring cans and hand-drawn distributors satisfactory results may be secured, it usually will be more economical to use large pressure distributors, horse-sweepers for the first brushing and, in some cases, horse-drawn or motor mechanical stone chip or sand spreaders.

Patching Wearing Course by the Layer Method. The repairs of small areas of the wearing course, varying in character from depressions of ½ in in depth to patches having depths equal to the thickness of the bituminous concrete, have been made by the layer method, especially in the case of Class A pavements. This method consists of coating the cleaned depression with bituminous cement, adding a layer of road metal and repeating the operation until the depression is filled. Altho satisfactory results have been obtained under expert supervision and other favorable conditions, usually there results an unstable patch which has been rapidly displaced if the pavement is subjected to heavy traffic, especially one including horse-drawn or motor trucks.

Patching Wearing Course with Cold Mixtures. Satisfactory results have been obtained by patching bituminous concrete pavements using mixtures of unheated road metal and either an unheated cut-back asphalt or a tar cement. Due to the crude manner of mixing employed, this method has been most satisfactorily used with bituminous concrete of Class A. The details of mixing and laying and the kind of material used in this method of patching are well covered by the following specifications of the Ohio State Highway Dept.

Method of Patching. "The depression or area to be patched shall be thoroly cleaned of all loose, matted dirt or foreign material, and swept clean of all dust. When clean and dry, the depression shall be painted with the same kind of bituminous material as is used in preparing the bituminous concrete. When the depression is deeper than 3 in, it shall be first filled to within 2 in of the road surface with No. 2 stone (see Sect. 15, Art. 11), which shall be thoroly tamped in place. The depression shall then be filled with bituminous concrete prepared as described below, in sufficient quantity to fill the depression to the level of the surface of the surrounding pavement after the bituminous concrete is thoroly compacted. The patch shall be covered with sufficient No. 6 grit (see Sect. 15, Art. 11) to prevent the bituminous material from sticking to the wheels of the roller, and then thoroly compacted by rolling. The surface shall be covered with No. 6 grit, or clean, coarse sand, to protect the patch while setting up.

"**The Bituminous Concrete** shall be prepared by one of the two following methods, using the same kind of aggregate as was used in the original construction of the road; also bituminous material same as original construction, that is, either tar or asphalt.

1. When an asphalt-bound road is to be patched, the bituminous concrete shall consist of a mixture of bituminous material A.C.B. and No. 4 size stone or slag (see Sect. 15, Art. 11) in the proportion of 1¼ gal of A.C.B. to 1 cu ft of aggregate. The aggregates shall be thoroly and uniformly mixed on a tight platform by hand methods or in a concrete mixer, until each particle of stone is completely coated with the bituminous material. After mixing, the bituminous concrete shall be stored, where it will be free from dust or dirt for 24 hr, or until the bituminous material stiffens sufficiently to bind when the patch is made. When required by the commissioner, a small amount of clean, coarse sand shall be added to the aggregate.

2. When a tar-bound road is to be patched, the bituminous concrete shall consist of a mixture of bituminous material T.C.B. and No. 4 size stone or slag in the proportion of ¾ to 1 gal of T.C.B. to 1 cu ft of stone. The aggregate shall be thoroly and uniformly mixed on a tight platform by hand methods or in a concrete mixer, until each particle of stone is completely coated with the bituminous material. After mixing, the bituminous concrete shall be stored, where it will be free from dust or dirt, for several days until the bituminous mixture stiffens sufficiently to bind when the patch is made.

"In either of the above methods the stone shall be dry when mixed with the bituminous material and neither stone or bituminous material shall have a temperature of less than 10° C (50° F) when mixed together.

"**Asphalt Cut-Back.** The material shall be a cut-back asphalt prepared in a still by compounding 35% of a distillate meeting the following specifications for distillate and 65% or an asphalt meeting the requirements as specified for Bituminous Material A-2, Sec. 6.2.

"The distillate shall have a specific gravity of not less than 0.736 nor greater than 0.765 at 25° C (77° F) and shall have an end point of distillation of 170° C (338° F).

"The cut-back asphalt shall conform to the following tests:

1. It shall be homogeneous in character.
2. It shall have a specific gravity of not less than 0.90 at 25° C (77° F).
3. When 20 g of the material are heated for 5 hr in a cylindrical tin dish approximately 2½ in in diameter by ¾ in high at a temperature of 163° C (325° F) the loss in weight shall be between 35% and 40%. The penetration, 5 sec, 25° C (77° F), No. 2 needle, 100 g weight, of the residue shall be not less than 3.5 mm nor more than 6.0 mm.
4. The specific viscosity as determined on the first 50 cu cm by means of an Engler viscosimeter at 25° C (77° F) shall be not less than 25 nor more than 35.
5. When distilled in an Engler distilling flask to 170° C (338° F) the material shall yield a distillate having a gravity of not less than 0.736 nor greater than 0.765 at 25° C (77° F).
6. The residue from the above distillation shall have a ductility, Dow mold, of not less than 30 cm.

"**Tar for Cold Application.** Bituminous material T.C.B. shall meet the following requirements:

1. It shall have a specific gravity of not less than 1.15 nor more than 1.20 at 25° C (77° F).
2. On extraction with carbon disulphide it shall contain not more than 15% nor less than 8% free carbon.
3. Upon ignition it shall show not over 0.5% inorganic residue.
4. When 240 cu cm of the tar are heated in an Engler viscosimeter to 50° C (122° F) and maintained at this temperature for at least 3 min, the first 50 cu cm which flow thru the aperture shall show a specific viscosity of not less than 3 nor more than 15.
5. When distilled by the method proposed by the Am. Soc. Test. Mat. not less than 15% shall distill below 235° C (455° F); not more than 35% shall distill below 300° C (572° F). The residue from the foregoing distillation shall have a melting point not greater than 75° C (167° F) by the cube method.
6. The tar shall be free from water.
7. All bituminous material used in a given construction shall be uniform in character, appearance and viscosity."

Plant Operation in Ohio, by Hinkle (37). "A very convenient way to handle work of this kind is to do all the mixing and storing of materials at one point, near the middle of the section of road to be repaired, and then use a wagon whose box is divided into compartments to hold a barrel of tar or asphalt for painting the surface, the bituminous concrete, sand for cover, etc, and have the wagon follow along as the work progresses. A central station, where the bituminous concrete may be mixed by machine, may be provided and all the bituminous concrete required for a district mixed in one place. The bituminous concrete can be hauled in trucks from the central plant and delivered to the repair crews working at various places on the road. While such a stationary plant is very practical under some conditions, it would not be practical where but a small amount of the mixture is wanted as here the mixing would likely be done by hand to better advantage on the road. Also where a large amount of the concrete is wanted on one road, the plant should be located on the road or at the delivery station of the materials for that road."

Penn. State Highway Dept. Practice by Biles (18), giving reasons for, and methods of, repairing.

"CRACKING OF THE SURFACE is one of the greatest as well as one of the earliest defects that may develop in bituminous pavements. This may be due to one cause or a combination of several causes. Frequent cases are noted in bituminous wearing surfaces which, altho apparently satisfactory mixtures in all other respects, contract

as the base contracts and crack open at exactly the same point as the foundation. Again, cases are noticed of otherwise satisfactory pavements which crack because of their failure to receive the amount of traffic necessary to give the pavement its full compression or to iron out and close up the surface after low temperatures have made it tend to open up by stretching the bituminous binder. A condition of the sort last described, however, may have been hastened considerably or even caused directly by what might be called improper design of the pavement in the first place. The bituminous surface mixtures expected to receive heavy traffic should be tough and fairly hard in order to resist displacement. Those designed for light traffic should be softer and more yielding, and this is accomplished by using a softer bitumen, that is, one of a higher penetration. Failure to do so means that as the pieces of mineral aggregate contract or shrink in volume during cold weather, they exert a spreading force in the surrounding bitumen, which it cannot withstand because of its lack of light fluxing oils and corresponding ductility or ability to stretch; in other words, pavements containing hard or non-ductile bituminous material will have a greater tendency to crack in cold weather. Similar results and even general disintegration of the wearing surface may have been produced by too little bitumen in the mixture, since this is largely a measure of the life and elasticity of the pavement, and similarly, overheated mixtures suffer a hardening and reduction of bonding power of the bitumen, with consequent tendency to crack and wear. Aside from faulty drainage, poorly proportioned mixtures and unsuitable ingredients contribute largely to the failures in this type of pavement. A cracked bituminous surface, unless the cracks are caused by some serious form of disintegration in the pavement, can be repaired by cleaning the cracks out thoroly and pouring them full of either a hot or cold bituminous material of the proper grade, and thereafter tamping or wedging stone chips into the crack, thoroly sealing it. If the crack is wide enough and the edges have crumbled or broken off, they should be cut down evenly and the opening filled and tamped with a mixture of the bituminous cement and stone chips in a proportion of 1 part bituminous cement to 9 parts chips, in sufficient quantity to insure complete closure.

"Pot-Holes and Depressions can be repaired by cutting out the affected areas down to the foundation and replacing with new mixture. The character of the bituminous material to use depends entirely upon the conditions in each case. Unless the repair work is extensive, it is not deemed advisable to use hot bituminous compounds in this work, not only from the standpoint of economy, but from a point of convenience as well. Small repairs in the proper season can be handled economically and efficiently with cold bituminous cement, and if the proper mixture is used in the regular working season excellent results can be obtained. It is conceded that hot bituminous repairs are not generally satisfactory when made at low temperatures, but in some places the avoidance of this practice has been carried almost to a fault. As an example, in some of the larger municipalities where defects have developed in the surface during the winter months, the affected portions have been removed and repaired with brick or stone block. This method is not only objectionable on account of the annoyance to traffic but, when the regular season for repairs arrives, it is usually found that additional work is required, occasioned thru the inequality of the surface. It has been stated by some of the advocates of this method that it is an assurance that the affected portions will not be overlooked when the repair work is taken up in the spring. It has been demonstrated, however, that where conditions are so acute that this method is warranted, there is justification for making special arrangement for preparing and placing a suitable bituminous mixture which will be more satisfactory in the interim and, tho probably not a complete success, will offer as good, if not better, opportunities to correct later than the first method which seems only to be justified when repairing cuts made in the pavements by public service corporations in the winter season.

Deterioration of Pavement Edges. "The wearing and deterioration along the edges of bituminous pavements where there is no header, is responsible for one of the most troublesome and expensive forms of repairs to roads of this type. The traffic continually irons out the surface along the edges and this spreading or flattening out produces a feather edge along the side. The moisture and foreign material tracked on from the shoulder soon attack the bituminous material and result in the crumbling or breaking away of the surface which occasions extensive repairs. This condition is more pronounced when the material in the shoulders is of a non-porous nature or is

poorly drained. In the repairs to the edges of a bituminous pavement not confined by headers, the first and most essential thing to do is to correct the cause, if possible. If the drainage of the shoulders or base is faulty, this should be taken into consideration first and ample provision made therefor. On shoulders which are composed of non-porous material, it is advisable to cut scuppers or small surface ditches at intervals of approximately 20 ft along the road and, in addition to this, the material immediately along the edge of the pavement should be replaced for a depth of a few inches with broken stone or gravel tamped into place to produce a more stable buttress for the new bituminous material. The patches should be made by removing the affected area and replacing with new mixture. Successful repairs should neither be above nor below the surrounding surface when finally compacted.

PLANT EQUIPMENT. "In municipalities where there is enough yardage to warrant a central mixing plant, this is the most satisfactory method of handling bituminous repairs. With every facility at hand to compound the mixture properly, more uniformity is assured and much of the personal equation resulting from separate organizations is eliminated. There are localities where possibly small portable mixing plants would meet the requirements and give satisfactory results. However, under ordinary conditions, the problem is generally a small town with probably several short streets or some other unit, such as a county or state, with continuous stretches of miles of interurban bituminous pavements or highways. In either case, it means one outfit or a number of outfits performing the repair work, which conditions give strength to the demand for simple and efficient methods. With trained men, good hot bituminous mixtures have been prepared by hand, but considering the chances taken in overheating the material, the careless proportioning and mixing, and the extra expense in connection with the handling of the equipment, etc, this method is not justified. The cold bituminous mixture with the proper material is the most economical and foolproof method for ordinary repairs. The material can be mixed on a regular mixing board, stock prepared for future use, if need be, and stored at convenient intervals along the road and, aside from the small tools, such as shovels, rakes and tampers, no other equipment is absolutely necessary. Repairs have been made with cold bituminous mixtures on extremely heavily traveled roads that are in excellent condition after four seasons of wear."

U. S. O. P. R. 1918 Specifications for Tar for Cold Patching, and Recommendations for Use.

"GENERAL. The tar shall be homogeneous.

"PHYSICAL AND CHEMICAL PROPERTIES. It shall meet the following requirements:

1. Specific gravity 25°/25° C (77°/77° F), 1.100 to 1.200;
2. Specific viscosity at 40° C (104° F), 40 to 70;
3. Total distillate by weight:
   To 170° C (338° F), not less than 2.0%;
   To 270° C (518° F), 15 to 25%;
   To 300° C (572° F), not more than 30.0%;
4. Total bitumen, soluble in carbon disulphide, not less than 80%.

"METHODS OF TESTING. Tests of the physical and chemical properties of the tar shall be made in accordance with the following methods:

1. Specific gravity: Bul. U. S. Dept. Agr., 314, p. 4.
2. Specific viscosity, on first 50 cu cm: Bul. U. S. Dept. Agr., 314, p. 7.
3. Distillation test: Bul. A. S. T. M. Standard Test D 20–16.
4. Total bitumen: Bul. U. S. Dept. Agr., 314, p. 25.

"NOTES: This specification provides for a material to be used in the repair of surface breaks, holes and depressions in bituminous bound and surface treated roads. It is intended to cover preparations consisting of gas-house, coke-oven or water-gas tars or pitches which have been rendered sufficiently fluid by the addition of distillates to enable them to be handled without heating.

"METHODS OF PATCHING. For surface breaks and shallow depressions or those which in general do not exceed ½ in in depth, a patch may be made by painting the bottom of the depression with the tar, and scattering over it a sufficient amount of stone chips to fill the depression. In repairing deeper depressions and holes, the old material should be removed to yield a clean bottom. The sides of the hole should be cut approximately vertical. A mixture of graded broken stone with just a sufficient amount

of tar to thoroly coat each particle should be prepared, and firmly tamped into the hole to form a neat patch in the surface. A thin layer of sand or screenings over the patch will prevent it from picking up under traffic."

Patching and Reconstructing Wearing Course with Hot Mixtures. The most efficient method of repairing bituminous concrete wearing courses is to use the same kind of mineral aggregate and the same kind of bituminous cement that was employed in the construction of the pavement. Usually, fulfilment of the above requirements necessitates the heating of the mineral aggregate as well as the bituminous cement. By this method of repairing, maximum homogeneity of the wearing course is obtained and sufficient stability is secured to prevent the newly laid bituminous concrete from being displaced by traffic. The efficiency of this system depends upon the kind of plant equipment and repair organization, and the location and character of the bituminous concrete pavements in a given system.

THE PATROL SYSTEM of maintenance generally is not applicable to this method of repairing due to the plant equipment required to manufacture suitable bituminous concrete.

THE MOBILE GANG SYSTEM has worked out satisfactorily by using either a stationary or portable plant. Under such conditions as exist in municipalities or in highway systems outside of urban districts such as the Ashokan Reservoir Division of the Board of the Water Supply of New York City, where 32 miles of one type of bituminous concrete has been constructed, the utilization of a stationary mixing plant and motor trucks for the transportation of the hot mix is justifiable on economic grounds. When, however, the bituminous concrete pavements are widely scattered thruout a county or state system of highways, the portable plant will prove economical.

The following plant equipment would prove satisfactory for the maintenance of 50 miles of bituminous macadam and bituminous concrete pavements well distributed over an area of, say, 2000 sq miles. The equipment should include a motor truck and a trailer. The truck would be used for transportation of broken stone, sand, cement, fuel, bituminous materials and small tools and accessories. A trailer should be permanently equipped with a small mixer, drier, and melting kettles. In many cases the following accessories could be used efficiently: A hand-drawn gravity distributor, pouring cans which distribute the material in the form of a sheet, conical pouring cans such as are used for the application of bituminous fillers, coarse fiber and bass fiber brooms, a heavy hand-drawn roller, tampers, smoothing irons, squeegees, a large hand power bellows, a small surface heater, and other small tools, such as shovels and picks. If large areas are to be repaired, a horse-drawn sweeper, a small pressure distributor, and a tandem roller should be included in the equipment.

English Patching Methods with Plant Mixed Bituminous Concrete by Hooley (38b). "Observation must be made after rain where holes or depressions appear and water stands. Each lengthman must ascertain to what extent water stands, and must then, by scratching with a strong nail around the edge of the water puddle, mark how much excavation will be necessary to raise the depression up to the adjoining surface. This mark must, directly the road is again dry, be marked deeper by a pick if the work of patching cannot be at once undertaken. When the work of patching is commenced, each lengthman must have a sufficient quantity of 1½-in and ⅝-in tarred material at hand to deal with the patch, and on no account must one patch be commenced before the other is finished and the road levelled. He must be provided with two sharp picks, a coarse and a fine brush, an 8-lb rammer, and a straight-edge.

"The top layer of material within the marked area must be thoroly excavated to a depth of slightly more than 1½ in, or a little deeper than the depression; the bottom must be left as rough by picking as possible. Every trace of loose or wet material must

be swept out with the coarse and fine brushes, so that a rough, clean base is presented with the edges shaped to a sharp arris to the remaining road surface, and, if possible, slightly deeper on the outside edge than the center of the patch. The arris edge must then be treated with a layer of ⅝-in and the center with 1½-in tarred material, every piece of the material being made to touch. Any overplus of ⅝-in must be swept towards the center and every crevice filled with ⅝-in. The whole must then be well and regularly rammed until perfectly level. This level will at once be found by the application of the straight-edge. On no account must any feather-edge be left. The patch must be in the hole, and on no account be made to overlap, for if overlapping takes place, the edges will at once break away and fret."

Maintenance of Asphalt Block Pavements by Morrison (48).

"There are three principal things to be guarded against in the maintenance and repair of asphalt block pavements: (1) Allowing small defects to go unrepaired until they grow into actual holes in the wearing surface; (2) making an incomplete, and therefore ineffectual, repair by simply plugging the hole and failing to make a repair of sufficient area to restore the surface of the pavement to its original grade and contour; (3) neglecting or failing to utilize the old blocks in a proper and effective manner.

"Blocks that are ten or more years old are generally hard and dry, the reason for which will be described later, and in taking up and relaying them the edges and corners are liable to be damaged. If the joints are simply filled with sand, the edges crumble under traffic, producing a rough and unsightly surface. The only proper method of treating the joints is by the use of an asphaltic filler. Where the joints are larger or the edges and corners badly chipped, they should be filled with dry trap rock grits before pouring the asphaltic filler.

"The joints should be made water-tight. The asphaltic filler is spread out by traffic, thus protecting the surface of the block as well as the joint. The importance of treating the joints in this manner cannot be overstated. Such a repair results in a smooth surface, which under the action of traffic renders the patch indistinguishable in a very short time, whereas a patch made with the same blocks, with sand-filled joints, generally produces a rough surface with a percentage of bad joints which are subject to deterioration under traffic during the winter. The cost of applying the asphalt filler, which will be described later, is small and insignificant when balanced against the benefits accruing from it. In making repairs to asphalt block pavements, the old blocks should be used to the utmost extent, and the new ones should be placed in continuous areas by themselves. The old blocks which are of the same formula, age and wearing quality will thus be brought together, and from the new blocks, laid by themselves, will be derived their utmost serviceability. Practically every whole block can be salvaged and efficiently used. This is true even where the blocks have one surface badly mutilated and are of unequal thickness, since the bad and irregular surface can be bedded in the mortar and the smooth surface of the blocks exposed to traffic.

"The brittle condition of the old blocks (due to the use of a very hard asphalt cement, which gradually grew harder with the lapse of years as the volatile matter in the flux oil evaporated) led to the inauguration of a series of experiments to determine a satisfactory and economical method of surface treatment which would soften the hard asphaltic cement and prevent the chipping of the blocks in winter. The method which produces the desired result is to dissolve a heavy bituminous oil in a volatile solvent and apply it to the surface of the old blocks in the form of a thin wash or paint coat, given one or more applications, as considered necessary. The solvent penetrates a considerable distance into the blocks and then evaporates, leaving a coating of heavy stable bitumen, which mixes perfectly with the old asphalt, softening and giving it new life while producing a malleable surface on the old blocks very similar to that produced by the formulas now used in the manufacture of new blocks. After the application of the paint coat the entire surface of the pavement should be covered with a very thin layer of dry, fine trap rock screenings, passing a ⅛-in screen; or any clean dry sand will answer the purpose if trap rock is not available. The fine trap rock, sand and dust serve the double purpose of preventing the oil from being picked up by the shoes of pedestrians and tires of vehicles, and, what is more important, cause the oil to be ground by traffic into the joints and inequalities of the surface. Where the joints are only slightly broken down this simple application is all that is needed to

restore the surface of an old asphalt block pavement to a satisfactory condition. The cost of this surface treatment when applied to large areas ranges from 2 to 4 cents per sq yd."

Brooklyn, N. Y., 1914 Specifications for Repair of Asphalt Block Pavements (48).

"The work shall consist of the removal of the present asphalt block pavement and mortar bed; the repair of the present concrete foundation; the repaving of the roadway with asphalt blocks made up in part by new blocks and in part by old blocks taken from the present pavement; the treatment of the surface of the old blocks and all work incidental thereto; all in accordance with the plans and specifications on file in the Bureau of Highways, and over such areas as the engineer may direct.

"The thickness of the mortar bed used under the culled blocks which are repaved over the above areas shall be approximately ½ in, but sufficient to bring the upper surface of the relaid blocks to an even grade with the adjacent pavement surface.

"The asphalt blocks forming the present pavement, as taken from the street, shall be carefully culled and blocks which show a depth of 1½ in or over and are otherwise suitable shall be piled separately and used for repaving. The old asphalt blocks which can be used again shall be used to repave such areas as the engineer may direct. In addition, the contractor shall furnish and lay, as directed by the engineer, new asphalt blocks, which shall conform in all particulars with the current asphalt block specifications of the Bureau of Highways, Borough of Brooklyn, which, so far as they apply, are made a part of this specification.

"The surface of the present pavement which has not been disturbed, and those areas which have been repaved with blocks culled from the present pavement, shall be thoroly broomed over with steel brooms and the joints cleaned and freed from all dirt and loose material. Into the joints between the blocks shall be poured quartz gravel, crushed granite or trap rock, which shall be clean, approximately cubical, free from all foreign materials and shall pass a ¼-in mesh sieve and be retained by a 20-mesh sieve. It shall be artificially heated and dried in proper appliances placed near the work before being placed in the joints, if required by the engineer.

"Immediately following the application of the gravel, the joints shall be poured with an asphaltic cement conforming to the following requirements: The block filler shall be a blown asphaltic oil product, or a residual asphalt: (1) It shall contain not less than 99% of bitumen soluble in carbon disulphide; (2) it shall contain not less than 98.5% of total bitumen soluble in carbon tetrachloride; (3) it shall have a penetration at 25° C (77° F), under a load of 100 g, for 5 sec, of not less than 55 nor more 75; (4) it shall have a penetration at 0° C (32° F), under a load of 200 g, for 60 sec, of not less than 25; (5) it shall have a penetration at 46° C (115° F) under a load of 50 g, for 5 sec, of not more than 200; (6) it shall have a ductility at 25° C (77° F) of not less than 5 nor more than 25 cm.

NOTES: "When the specifications were prepared it was expected that the work would be done in midsummer and that the treatment of the joints, as previously described, would be sufficient for their protection, and that the summer traffic would distribute the asphaltic filler over the surface of the blocks sufficiently to protect them against any tendency to pit or rough up during the succeeding winter. This treatment would undoubtedly have been sufficient if the work had been done in midsummer, but as it was actually done in the cold weather of late November it was considered advisable to add to the treatment described in the specifications a surface treatment of the entire area of old blocks. This consisted of a paint coat composed of crude oil and a heavy asphaltic maltha of about 12° B, mixed half and half, applied hot and squeegeed over the surface, followed by a thoro sprinkling with fine trap rock grits and dust passing a 20-mesh sieve."

Maintenance Record of Class A Bituminous Concrete Pavements in Jamaica, N. Y. (67b).

This experimental road, 25 ft wide, was built in Aug. and Sept., 1911. The work consisted in resurfacing a 2000-ft length of badly worn, water-bound macadam pavement on Hillside Ave. Before the experimental work was begun the old macadam surface was scarified and rebuilt to a crown of ⅜ in per ft by addition of material and rolling. The aggregates used in all the experiments were clean, crushed trap rock, screened according to the following grades: ¾-in stone, passing 1¼-in circular opening and retained on ⅝-in opening; ⅜-in stone screenings, from which dust had been removed.

A Traffic Census in 1911 showed an average of 1493 vehicles per day of 24 hr, 25% of which was horse-drawn wagons and motor trucks. On Sat., May 18, Sun., May 19, and Mon., May 20, 1912, the traffic was 2995, 5199 and 1795 vehicles, respectively; the average number of horse-drawn wagons and motor trucks on May 18 and 20 being 460.

Asphaltic Concrete constructed with fluxed native asphalt used in the mix and for the seal coat. Details of construction were as follows: Compacted depth 2 in; proportions, 7.5 cu ft of ¾-in dried stone to 5.5 gal of A. C. heated to 167° C (340° F); surface finished with seal coat of A. C. and ½-in stone.

Record of condition and maintenance on dates given. May, 1912, excellent condition, except at station 5 + 00, a slight depression due to wear; repaired by applying an oil-asphalt seal coat. June, 1913, slightly wavy, otherwise in excellent condition. Jan., 1915, all in good condition, except in places where house sewer connections were made. Jan., 1916, same as when last inspected.

Tar Concrete constructed with refined coal tar used in the mix. Details of construction were as follows: Proportions, 10 cu ft ¾-in dried stone to 7 gal tar; for the seal coat, coal tar was used for the first 150 ft, oil-asphalt for the second 150 ft.

Record of condition and maintenance on dates given. May, 1912, seal coat of oil-asphalt in good condition; seal coat of refined coal tar entirely worn off; new seal coat of light coal tar at the rate of 0.28 gal per sq yd applied from station 8+00 to station 8+70 and from station 8+70 to station 9+50, seal coat of tar-asphalt preparation applied. June, 1913, slightly wavy; otherwise in excellent condition. Jan., 1915, section in excellent condition, except for wavy surface in places and for a few small spots where seal coat was worn off. Jan., 1916, wavy on sides; center in good condition; on south side surface crumbling where seal coat has been worn off.

Excerpt from report of committee of supervising engineers, covering investigations made in March, 1916. "The east end, which carries an asphalt seal coat, is in excellent condition. The surface is much smoother than where a tar coat has been applied, and the seal coat is still intact. At the present time this portion of the experiment is probably the most satisfactory from the standpoint of serviceability that has developed in connection with the entire series of experiments."

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SECTION 17

SHEET-ASPHALT AND ROCK ASPHALT PAVEMENTS

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SHEET-ASPHALT PAVEMENTS

ROCK ASPHALT PAVEMENTS

SHEET-ASPHALT PAVEMENTS

GENERAL DATA

1. Description and Historical Development

Description. Sheet-asphalt pavements differ broadly from other types of bituminous pavements by having a wearing surface, the mineral aggregate of which contains no particles which would be retained on a ¼-in screen. As usually laid they consist of two distinct courses laid on a foundation of old macadam, bituminous concrete or Portland cement-concrete.

1. Binder course: Composed of asphalt cement, broken stone and usually sand. Sometimes a paint coat composed of asphalt dissolved in naphtha is applied to the surface of the concrete foundation and the binder course is omitted.
2. Wearing course: Composed of sand, filler and asphalt cement.

Historical Development. Mixtures of coal tar with sand, gravel, broken stone, ashes, and materials of a similar nature were employed in the United States prior to 1865 on sidewalks and cross-walks. They undoubtedly were the first step in the development of the modern sheet-asphalt pavement, as the general principle involved, of mixing hot sand with a bituminous cementing material, is substantially the same in both cases. This is also true of the method of laying. A mixture of this kind was laid on one of the highways in Prospect Park, Brooklyn, N. Y., in 1867 and was so successful that a similar pavement was put down the following year on Diamond St. in Brooklyn. The foundation of this pavement was 5 in thick and was composed of 2-in broken stone, sand, coal ashes and tar. The wearing surface was of similar composition except that the stone used in it was not larger than 1 in in its greatest dimension. This is probably the first street in the United States which can be considered as having had a bituminous pavement. Shortly after 1870 a number of coal-tar pavements were laid in Washington, D. C. The base used was broken stone, 4 to 6 in in thickness, which was cemented together with coal tar. This base was covered with a binder course averaging about 1 in in thickness and composed of gravel, fine broken stone and coal tar. Generally speaking, the foundation and binder course were substantially the same in all cases but the wearing courses differed considerably and were laid under numerous patents. Some of these pavements were very good and some were very bad but even the best of them became very soft in summer and could not be regarded as generally satisfactory, and where the traffic was at all considerable their cost of maintenance was high. This appears to be the first recorded development of the modern binder course. In 1870, E. J. deSmedt, who was familiar with the art of laying bituminous rock pavements as developed in Paris, laid an asphalt sand mixture in front of the city hall in Newark, N. J., which proved successful. This was undoubtedly the first asphalt pavement laid in the United States, altho its exact composition is in doubt. It was followed by similar pavements in New York City and Philadelphia. As a result of these, Pennsylvania Ave. in Washington, D. C., was paved with an asphalt sand mixture in 1877. The use in Washington of this type of pavement rapidly increased and other asphalts began to be used for the same purpose and from this beginning the use of sheet-asphalt pavements rapidly developed thruout the country. It was not until many years later that sheet-asphalt pavements were laid in England and on the Continent.

2. Characteristics

Sheet-asphalt pavements are smooth, non-productive of dust, almost noiseless, waterproof, non-absorbent and easy to clean. They are capable of sustaining very heavy traffic and also last well under light traffic. They are therefore well adapted for business and residence streets and the facility with which they may be kept clean makes them especially desirable in tenement districts. They are easy to repair and offer but slight resistance to traffic. They are somewhat softer in summer than in winter but when properly laid never become too soft for use even in the hottest weather. When dry and clean they are not slippery and their slipperiness in moist or drizzly weather is largely due to the presence of a thin film of mud caused by the collection of street detritus, and this can be greatly reduced by washing or keeping them clean. For this reason they are less slippery in a heavy rain than in a drizzle. Horses accustomed to granite block pavements instinctively put their hoofs down and slide them until they obtain a foothold in the crevices of the pavement. As there are no such crevices in a sheet-asphalt pavement, it takes a little time for them to become accustomed to it but they soon learn to adapt themselves to a smooth surface.

While, as previously stated, sheet-asphalt will sustain a very heavy traffic, this statement applies more especially to a traffic largely composed of quick moving, light to medium loaded vehicles, such, for instance, as prevails on Fifth Ave., New York City. It is not the most suitable type of pavement for a very dense, slow moving, heavily loaded traffic. Wood block and granite block will outlast it under these conditions. It will not give satisfaction where there is practically a total absence of traffic, as it then is liable to develop cracks, apparently requiring the kneading action of traffic to equalize the stresses set up by contraction and expansion and to keep it in proper condition. It is entirely suitable, however, for traffic varying from the light delivery traffic of residence streets to the dense but quick moving traffic of Fifth Ave., New York City, or the Thames Embankment, London. Very recent figures as to the traffic on Fifth Ave. are not available, but a record taken between 33rd and 34th Sts. during the months of Nov. and Dec., 1904, shows it to be heavier than on the Thames Embankment, and is given below:

Tonnage per 11 hr	19 274.47
Average tonnage per lin ft of width per 11 hr	481.85
Average tonnage per hr	1 752.20
Average number of vehicles per 11 hr	11 787.00
Average tonnage per vehicle	1.64

On account of their smoothness, sheet-asphalt pavements are not suitable for use on excessive grades. Generally speaking, streets carrying a fair amount of traffic can be paved with asphalt if the grade does not exceed 6%. In some cases, where the traffic was very light and a smooth pavement was considered essential, it has been laid on grades running up to 10 and 12%, but this is rather exceptional. Where the traffic is heavy, a 3 to 4% grade is usually considered as the limit. In most of the largest cities of the United States the maximum grades on which this type of pavement is laid vary from 4.5 to 8%, regulated largely by the traffic and climatic conditions.

3. Foundations

As a sheet-asphalt pavement has not sufficient internal stability to permit it to bridge over depressions or soft spots and as excessive vibration will tend to produce rapid disintegration, it must be supported by a rigid and unyielding foundation of sufficient strength to carry the traffic. The character of the foundation required will depend upon the following conditions: Traffic, climate, character of subsoil and drainage. The strength of the foundation must be directly proportional to the weight of the traffic. In cold climates, where the ground freezes to a considerable depth in winter, the spring thaws produce a very unstable condition of the subsoil and the foundation in such cases must be stronger than is required in climates where there is little or no frost. A well drained sandy soil is much less affected by these temperature changes than is a heavy clayey soil. The treatment of the subsoil, therefore, is of primary importance, especially where the traffic is heavy. It should be drained and thoroly compacted by rolling to such an extent that it will be free from displacement thru settlement or frost. All soft spots should be excavated and filled with suitable material and all trenches must be thoroly backfilled. In sandy soils this may be done by the aid of water; in clayey or heavy soils they must be slowly filled and carefully tamped for each 6 in of fill. In certain localities in the northwestern portion of the United States and Canada very heavy clay soils are found. In winter these frequently develop cracks from 4 to 5 in in width and heave very badly. In such cases cross trenches should be dug every 25 or 30 ft and filled with coarse broken stone and connected with longitudinal trenches at the side of the street, similarly filled and draining to catch basins. It is inadvisable to lay concrete directly on such a soil. Sand and gravel should first be spread upon it to such a depth that when rolled it will form a layer 3 to 4 in in thickness and the concrete should be placed on this. Where the subgrade is marshy or swampy or consists of a fill made on such ground, and it is impracticable to thoroly drain it, concrete of sufficient strength must be employed to bridge over soft spots and distribute the load over as great an area as possible. Depending upon traffic, subsoil and climatic conditions, a number of different types of foundations have been successfully employed, such as old macadam; broken stone, either rolled dry or cemented together with some form of bituminous cement; old cobblestone; Belgian block or granite block pavements; old brick or asphalt block pavements; bituminous concrete; natural cement-concrete and Portland cement-concrete.

Broken Stone Foundations. Where the traffic is light, the climate mild, and the subsoil conditions favorable, old macadam roads which have been properly constructed and drained have given very excellent results as foundations. In some cases, notably the Thames Embankment in London, a foundation of this kind covered with an asphalt pavement has sufficed to carry a very heavy traffic, but its use under severe conditions is to be deprecated and more failures than successes have resulted from it. Stones screened out from an old broken stone road-bed are always well rounded on the edges, showing that they move under traffic and that a broken stone road, however good, does not form a rigid foundation. Many so-called broken stone roads have been constructed without any attention to drainage by simply dumping stone on top of old earth roads and consolidating it by traffic with little or no preliminary rolling. These should not be regarded in temperate climates as suitable foundations for any

permanent type of pavement. Where a broken stone road is used and the grade will permit, it is far better to build up depressions and reduce the crown if necessary by adding broken stone on the quarters and thoroly compressing it with a roller. Any attempt to remove portions of the surface by scarifying it will seriously disturb the bond of the broken stone and impair the consolidation and solidity resulting from years of travel.

Old Pavements of Brick, Granite, etc, should not be used as a base if, owing to height of curb or any other reason, it is necessary to reset them. In their original condition they are satisfactory where the traffic is not heavy. Relaid blocks are not rigid and have a tendency to rock and sheet-asphalt pavements laid on such foundations in New York City have rapidly disintegrated wherever they were exposed to heavy traffic. In almost every case the active centers of disintegration have been found to be directly over blocks which were not firmly bedded. If a foundation of this kind is to be used, the relaid blocks should first be subjected to travel for a considerable period of time and any blocks which do not thus become firmly bedded should be reset. Rolling and ramming them will not produce the desired results.

Cement-Concrete Foundations. Where the traffic is heavy, no base but Portland cement-concrete should be used and its thickness should depend upon local conditions. The requirements of modern traffic are constantly increasing in severity, and where a few years ago 6 in was considered ample, 9 in is in many instances now required. In London, all streets subjected to motor-bus traffic are being provided with 9-in concrete foundations, as 6-in foundations were found to shatter under traffic impact. In some cases 6 in of reinforced concrete is being tried, but this has hardly passed the experimental stage as yet. Where the traffic is comparatively light and the subsoil at all unfavorable, it is much better to use 4 or 5 in of concrete than to experiment with questionable macadam. A permanent and adequate base can always be used again when the pavement requires resurfacing, whereas any serious failure of the base requires a complete reconstruction of the street. Many authorities advocate the roughening of the upper surface of the concrete so that the pavement may key into the depressions thus formed and in this way reduce the tendency to shoving. Various methods of producing this roughened surface are employed. In some cases cross depressions are made by the use of pieces of timber embedded in the concrete while wet and subsequently removed. In other cases the concrete is not tamped sufficiently to fill all the surface voids with mortar, thus leaving a rough stone surface. Broken stone is sometimes sprinkled over the surface of the concrete just before it acquires its initial set. Special rake-like implements are also used to rake over the surface and score it before it has set. While it is true that pavements as a whole sometimes slide on a smooth base, exhibiting when taken up a slickenslide effect, it appears very questionable whether any pavement which lacks inherent stability to such an extent that it will shove up to an undesirable degree under traffic, will have its resistance to this action markedly increased by roughening the concrete which lies 3 in below its surface. A reasonably smooth concrete is favored as it tends to produce a more uniform thickness of pavement. Proper selection and grading of the mineral aggregate will prevent shoving. Where street-car rails are present in a street, they must be placed on rigid foundations and manholes and boxes must be similarly treated. Any excessive vibration in them will destroy the pavement adjacent to them and in many cases will permit the entrance of water between the pavement and the concrete. The usual

proportions for concrete vary from 1 : 2 : 5 to 1 : 3 : 6, altho with properly graded stone, such as crusher run passing a 2-in screen and retained on a ⅜-in screen, in which the voids are comparatively small in size, the proportion of stone may be increased considerably and the resulting concrete will be better and stronger in every way and will be much easier to compact by ramming and less liable to segregation. Bituminous concrete is in most cases more expensive than cement-concrete and has no great bridging strength. When used, therefore, it must be relatively thicker than would be necessary with a Portland cement-concrete and its use on unfavorable subsoils is not to be recommended.

MATERIALS

4. Sands

Essential Characteristics. Sand constitutes from 75 to 80% of a sheet-asphalt pavement and takes practically all the wear resulting from traffic. Sand for paving work, therefore, must be hard, clean grained and moderately sharp and must have a suitable mesh composition. The surfaces of the grains must be of such a character that asphalt cement will satisfactorily adhere to them. A careful examination under the microscope should therefore always be made of all sands proposed for use. This must be supplemented by a sieving test. Hardness is necessary in order that the grains may not crush to an undesirable extent under traffic. For this reason sands composed almost wholly of quartz grains must be selected. Sands composed largely of calcareous grains or grains composed of silicates are not suitable for paving purposes altho where the traffic is very light and the climatic conditions favorable and no other kinds have been available, they have been used with fairly successful results. The surfaces of the grains must be reasonably free from fine dust of such a character that it will bake on them when heated and prevent the asphalt cement from adhering to them with the requisite tenacity. Sharpness is essential in order that the grains may key together to such an extent as to offer strong resistance to the shoving action of traffic. A sand composed entirely of spherical grains would have so little inherent stability that a pavement made with it would rapidly form into waves under the action of traffic.

The Mesh Composition of Paving Sands is Determined by passing them successively thru sieves having various square apertures.

The following method for making a mechanical analysis of sand or other fine highway material, except for fine aggregates used in cement-concrete, was adopted in 1916 by the Am. Soc. Test. Mat.

Meshes per Lin In (2.54 Cm)	Diameter of Wire	
	In	Mm
10	0.02700	0.68580
20	0.01650	0.41910
30	0.01375	0.34925
40	0.01025	0.26035
50	0.00900	0.22865
80	0.00575	0.14600
100	0.00450	0.11430
200	0.00235	0.05969

"The method shall consist of (1) drying at not over 110° C (230° F) to a constant weight a sample weighing 50 g; (2) passing the sample thru each of the following mesh sieves (Am. Soc. Test. Mat. standard sieves) (Note: The order in which the sieves are to be used in the process of sifting is immaterial and shall be left optional; but in reporting results the order in which the sieves have been used shall be stated); (3) determining the percentage by weight retained on each sieve, the sifting being continued on each sieve until less than 1% of the weight retained on each sieve shall pass thru the sieve during the last minute of sifting; and (4) recording the mechanical analysis in the following manner:

Passing 200-mesh sieve..................................	......%
Passing 100-mesh sieve and retained on a 200-mesh sieve......	......%
Passing 80-mesh sieve and retained on a 100-mesh sieve......	......%
Passing 50-mesh sieve and retained on an 80-mesh sieve.....	......%
....	......%
	100.00%

Sometimes, in sifting a sand it is first placed on the 200-mesh sieve and the amount passing thru that sieve is determined. The residue left on that sieve is then placed on the 100-mesh sieve and the amount passing thru it is next determined and so on thru the entire range of sieves. In this way the individual percentages will add up to 100. It is customary to speak of the grains passing the 200-mesh sieve as 200-mesh material or grains; that passing the 100-mesh sieve as 100-mesh material or grains, and this practice is followed thruout the entire range of sieves. The proper mesh composition of a sand varies with the traffic to which the pavement is to be subjected. In light traffic pavements, a coarser sand can be used than in heavy traffic pavements. This will be discussed at length under the theory of sheet-asphalt pavements.

Standards for the Mesh Composition of a Paving Sand are given below:

	Light Traffic		Heavy Traffic	
Passing 200-mesh sieve......	0 to 5%		0 to 5%	
Passing 100-mesh sieve......	10 to 15%	18 to 25%	10 to 25%	25 to 40%
Passing 80-mesh sieve......	6 to 15%		10 to 20%	
Passing 50-mesh sieve......	10 to 40%		5 to 40%	
Passing 40-mesh sieve......	10 to 30%		5 to 30%	
Passing 30-mesh sieve......	10 to 20%		10 to 15%	
Passing 20-mesh sieve......	10 to 15%		5 to 10%	
Passing 10-mesh sieve......	5 to 12%		2 to 8%	
Passing 8-mesh sieve......	0 to 5%		None	

It is but seldom that a single sand can be found which will fulfil these requirements. Mixing must therefore be resorted to and ordinarily a mixture of two sands will be all that is required. In some cases three and even four sands have been mixed before the necessary mesh composition was obtained. When more than one sand is being used it sometimes happens that the only available supply of a certain grade is composed of grains that are not wholly satisfactory as to composition or sharpness. Unless such a sand is wholly unsuitable its admixture with other sands of more satisfactory character will often remove what would be a valid objection to its use if it were employed alone.

Typical Examples of Admixtures of Two Sands are given below:

	1	2	3	4	5	6
Passing 200-mesh sieve	1%	0%	1%	6%	1%	3%
Passing 100-mesh sieve	23%	0%	15%	36%	1%	15%
Passing 80-mesh sieve	21%	0%	14%	37%	2%	16%
Passing 50-mesh sieve	48%	5%	34%	18%	38%	30%
Passing 40-mesh sieve	3%	7%	4%	2%	15%	10%
Passing 30-mesh sieve	4%	22%	10%	1%	18%	11%
Passing 20-mesh sieve	....	34%	11%	....	15%	9%
Passing 10-mesh sieve	....	23%	8%	....	10%	6%
Retained on 10-mesh sieve	....	9%	3%	....	....	....
	100%	100%	100%	100%	100%	100%

(1) Sand A. (2) Sand B. (3) Mixture of two parts of sand A with one part of sand B, satisfactory as to mesh composition. (4) Sand C. (5) Sand D. (6) Mixture of two parts of sand C with three parts of sand D, satisfactory as to mesh composition.

A Typical Example of the Admixture of Three Sands follows:

	7	8	9	10
Passing 200-mesh sieve	1%	13%	....	3%
Passing 100-mesh sieve	13%	45%	1%	16%
Passing 80-mesh sieve	11%	38%	15%	17%
Passing 50-mesh sieve	38%	2%	24%	28%
Passing 40-mesh sieve	13%	1%	15%	11%
Passing 30-mesh sieve	13%	1%	11%	10%
Passing 20-mesh sieve	11%	....	10%	9%
Passing 10-mesh sieve	....	....	24%	6%
	100%	100%	100%	100%

(7) Sand E. (8) Sand F. (9) Sand G. (10) Mixture of 9 parts sand E, 8 parts sand F, 4 parts sand G, satisfactory as to mesh composition.

Surface Character of Grains. This consideration is of the highest importance as it vitally affects the cementing qualities of the asphalt cement, and if this fails the entire pavement fails. The best sands in this respect are those which have rough, pitted surfaces similar to the Cowbay sands. Those which have been polished and worn smooth on the surface are not so desirable, as they will not take as thick a coating of asphalt cement. This is also influenced by the composition of the grains. Limestone grains are soft and porous and generally undesirable in paving work but a coating of asphalt cement adheres very strongly to them. Flint grains are extremely undesirable, as they take a very thin coating of asphalt cement and it does not adhere strongly to them. Some of these peculiarities in the attraction of certain types of grains for asphalt cement and *vice versa* are not easy to explain, as surfaces apparently identical act very differently in this respect. To be on the safe side, choose clean quartz grains with comparatively rough and pitted surfaces and avoid those having coated or polished surfaces and composed of flint. Where undesirable sands have to be used they should be mixed at as high a temperature as possible without injuring the asphalt cement and the time of mixing should be increased, thus insuring as far as possible satisfactory coating of the grains and adhesion of the asphalt cement to them.

Sources of Supply. Sand is finely divided rock detritus and has usually been deposited in the place where it is found by water action. Where the current has been swift or the water violently agitated, coarse sand is usually deposited, the finer grains being deposited from comparatively still water. Wind is also an important agency in the movement of sand, as witness shifting sand dunes in many localities. Air currents at high velocity will transport very coarse sand and even gravel, while at lower velocity only fine sand will be displaced. These facts often indicate where fine or coarse sands may be searched for with hope of success. In protected areas and where eddies are formed along river banks, deposits of fine sand will usually be found. Where the flow of the current is unrestricted the bed of the stream will usually produce gravel or coarse sand. Variations in current velocity due to natural causes will frequently produce very great changes within 24 hr in the mesh composition of sand dredged from a river or bay. According to the localities in which they are found, sands may be classified as follows: Beach sands, from sea and lake shores; river sands; and bank or pit sands.

Beach Sands from the Sea-shore are usually unsuitable for paving work. The grains are often polished and rounded to an undesirable extent, altho this is not always the case. They are usually composed largely of 80 and 50-mesh particles and if used would therefore require mixing with both fine and coarse sands to produce a satisfactory mesh composition.

Beach Sands from Lake Shores are frequently used in paving work. The grains of which they are composed are usually more rounded than is the case with bank sands, but in many instances this action has not taken place to an undesirable extent. The mesh composition of sands of this type does not ordinarily show such an excessive accumulation of 80- and 50-mesh grains as do sea beach sands. They are of course deposited thru water action, but this is ordinarily less violent and continuous than on the sea-shore, as there is no tidal action. Even when more rounded than wholly desirable, the admixture with them of sharp pit sands is frequently sufficient to remove this objection. Suitable paving sands are obtained in large quantities from Lake Michigan, Lake Erie, Lake Ontario and Lake Pontchartrain, typical siftings of which are given below:

	Lake Michigan	Lake Michigan	Lake Erie	Lake Ontario	Lake Pontchartrain
Passing 200-mesh sieve	1%	10%	1%	2%	0%
Passing 100-mesh sieve	3%	55%	9%	4%	0%
Passing 80-mesh sieve	5%	23%	20%	41%	1%
Passing 50-mesh sieve	31%	6%	39%	39%	25%
Passing 40-mesh sieve	20%	4%	20%	7%	50%
Passing 30-mesh sieve	15%	2%	6%	4%	19%
Passing 20-mesh sieve	13%	0%	3%	2%	4%
Passing 10-mesh sieve	12%	0%	1%	1%	1%
Retained on 10-mesh sieve	0%	0%	1%	0%	0%
	100%	100%	100%	100%	100%

River Sands are found either in beaches or in the beds of streams. In the latter case they are usually obtained by dredging, altho centrifugal pumps are also employed to a large extent for this purpose. They form a very important source of supply for paving work and are very varied

in character. River sands generally possess strongly distinguishing characteristics peculiar to the particular river from which they are obtained. This is due largely to the different rock formations from which they were derived and the prevailing conditions of flow, shape and kind of river bottom, etc. Attention must be called to the peculiarities of many of the river sands obtained in the United States in the Mississippi Valley. The bitumen of an asphalt cement does not appear to adhere to them as strongly as it does to sands from eastern or western rivers and mixtures made from them will carry less bitumen and usually mark up to an undesirable extent in hot summer weather, even tho they are entirely satisfactory from the standpoint of mesh composition.

Bank or Pit Sands are differentiated from the other types previously described by not having been deposited by recent or present action. Their original derivation includes every known source of origin and method of deposition; by the agency of river, sea, glacial or wind action. Bank sands cover a wider range of mesh composition than do river or beach sands and are therefore of the greatest value in the paving industry. They vary from what is really a fine gravel to the wind-blown sands of the far west, many of which latter are almost entirely composed of fine quartz particles which will pass a 200-mesh sieve. Where a fine tempering sand is required carrying high percentages of 100 and 80-mesh grains it is usually sought for and found in bank or pit deposits. When digging sands from a bank or pit, it is essential to see that the deposit is properly stripped and the top layer of loam removed from it; otherwise, as the face of the bank is cut into, the loam will fall down and become mixed with the sand. In some instances these deposits are stratified in comparatively thin layers so that by careful selection almost any desired mesh composition can be obtained from a single pit. Careful working of such a deposit is necessary to insure getting the proper proportion from the various strata, otherwise hopeless irregularity in output will result. Glacial sands are found in those parts of the country which during the Glacial Period were covered with an ice sheet. Bitumen appears to adhere with great tenacity to sands of this character, notably those obtained from Cowbay and other localities on the north shore of Long Island, N. Y., and such sands have been used with great success in paving work in New York City. The presence of undesirable quantities of clay or loam render many bank sands unsuitable for paving work, as this bakes on the surface of the grains sufficiently to adhere to them during the mixing process, thereby preventing the bitumen coating from coming in close contact with the true surface of the larger grains altho they may appear to be well coated. Under stress of service this baked coating is liable to come off and carry the bitumen with it. In other cases the clay or loam bakes into small balls of sufficient tenacity to pass thru the mixer without breaking up. These are coated on the outside with bitumen, but when laid in the pavement break open under traffic, revealing a mass of loose, uncemented material which washes out on the first application of water. This leaves a pit in the surface in which water accumulates and carries on its disintegrating action. Where only clayey sands are available, they may be rendered suitable for use by washing them. Certain sands have their grains more or less coated with a ferruginous cement, notably the red sands of New Jersey. This is also the case with many of the sands associated with the London gravels. An asphalt coating applied to these English sands has frequently completely washed off in less than a month and this has justly caused this

type of sand to be regarded with suspicion altho cases have occurred where entirely successful pavements have been laid with them. Sands in which the grains are largely composed of flint should be viewed with extreme suspicion, as it is difficult to get the bitumen to adhere properly to them. In a limited number of instances artificial sand produced by crushing stone has been successfully used by itself or mixed with natural sand in paving work.

Voids in Sand. Before the generally accepted grading for paving sands was determined, the question of voids was possibly regarded as of greater importance and interest than at the present time. It was at first considered that the total percentage of voids in a sand should be as low as possible and that all the voids should be completely filled with asphalt cement. Of recent years, however, the tendency has been to keep the voids as small in size as possible and use sufficient asphalt cement to thoroly coat all the particles regardless of whether or not this completely filled the voids. A solid block of stone would possess no voids at all, but it would not be a sheet-asphalt pavement; also, of two sands having approximately the same mesh composition and different percentages of voids, the one to be preferred would usually have the larger total percentage of voids and yet have them smaller in size than the other. So many considerations enter into the selection of a sand for paving use that there is a danger of too great attention being given to the subject of voids if one becomes an enthusiast on that subject. From a theoretical standpoint a sand composed of spheres of the same size should have approximately 26% of voids, but in practice it is impossible to obtain this figure owing to the difficulty of compacting the spheres to the maximum point and the nearest approach to it has produced a mixture showing 31% of voids. Where the grains are of uniform size the percentage of voids will vary with the shape of the grains but not with the size of them. This is clearly shown by the following table by Richardson (7).

Voids in Different Sizes of Crushed Quartz

	Voids
Passing 6-mesh sieve and retained on 10-mesh sieve	43.3%
Passing 20-mesh sieve and retained on 30-mesh sieve	43.4%
Passing 90-mesh sieve and retained on 100-mesh sieve	44.2%

Generally, rounded grains will pack more closely than sharp grains but, as already noted, rounded grains are not desirable. Where the grains consist of particles of varying size, the voids are lower than where they

	Percent Passing Different Sieves								Weight per Cubic Foot, Hot		Voids, Hot	
	200	100	80	50	40	30	20	10	Loose	Tamped	Loose	Tamped
Buffalo	17	24	15	24	10	4	4	2	98.5 lb	108.0 lb	40.3%	34.6%
Omaha, Neb.	5	13	34	31	8	3	4	2	.....	109.7 lb	35.8%	33.5%
Chicago	2	74	23	1	..	..	.	.	93.5 lb	100.3 lb	46.3%	39.2%
Detroit	2	10	23	59	4	2	.	.	97.2 lb	106.6 lb	41.1%	35.4%
Kansas City, Kan	10	15	23	44	6	1	1	.	97.4 lb	106.8 lb	41.0%	35.8%
Long Island Bank	10	12	8	27	15	12	7	9	100.3 lb	110.8 lb	39.2%	33.0%

are all of one size, and, as is to be expected, the finer sands usually show a higher percentage of voids than the well graded coarser ones carrying a reasonable percentage of fine material. This is shown by the preceding table by Richardson (7).

The addition of limestone dust or filler up to a certain point will still further reduce the voids in a sand but beyond that point they will gradually increase. The critical point appears to be approximately that where the amount of added dust exceeds the voids originally present in the sand. The addition of approximately 36% of filler to a sand originally containing 36% of voids will reduce them to approximately 20%, but it is not practicable or advisable to use this amount of filler for reasons which will be explained later. In calculations involved in the determination of voids the specific gravity of the particles in a quartz sand is usually taken as being 2.65.

Prospecting for Sand. Sand dealers who have not been accustomed to furnishing paving sand should be approached with the explanation that concrete or mortar sand is not being sought, as this type of sand is too coarse for paving work. It should be impressed upon them that something much finer or softer is desired. In many cases they consider that an asphalt sand is a loamy sand, tho this is really not the case.

5. Fillers

Essential Characteristics. This is used to fill in the interstices between the grains of sand in the wearing course and render it more compact and dense. Fineness is therefore an essential requirement. As very little of the sand used passes a 200-mesh sieve and as a considerable quantity of it does pass a 100-mesh sieve, it is apparent that the bulk of the filler should pass a 200-mesh sieve. Most specifications require that at least 66% of the filler shall pass a 200-mesh sieve. The finer the portion which passes the 200-mesh sieve the better the filler and two fillers, both showing the same amount of 200-mesh material, may vary very greatly in this respect. Generally speaking, a filler should be free from organic matter, should be composed of particles to which bitumen will adhere readily and should be capable of packing solidly together when dry. This last property adds greatly to the stability of the mixture to which the filler is added.

Materials Used as Fillers. A great variety of materials have been used as fillers, including rock dust of almost every sort, Portland cement, natural cement, ground silica, slacked lime, clay, marl, fine sand dust from dust collectors and ground waste lime from beet sugar factories. Of the different varieties of rock dust, ground limestone is undoubtedly the best and has been used more extensively than any other filler. For ordinary traffic conditions there is probably nothing better. It packs well when dry and asphalt cement adheres to it tenaciously and is to a certain extent absorbed by it. For streets carrying very heavy traffic, Portland cement or a mixture of Portland cement and limestone dust, is probably superior to limestone dust alone, as they undoubtedly add to the stability of the mixture and seem to increase its wear resisting qualities. The reason for this is not well understood, but a mixture made with a Portland cement filler will rake stiffer and stand up with a more vertical face when dumped from the wagon than will an otherwise exactly similar mixture made with a limestone dust filler. Natural hydraulic cement has been used with some success, but a number of unfavorable results have been attributed, perhaps unjustly, to its use and at the present time it is seldom employed. Ground

silica or quartz has been largely used in past years in pavements in New York City but it has fallen into disuse. Bitumen does not adhere to it as well as it does to limestone dust or Portland cement and mixtures made with it do not resist water action as well as do those made with the other two fillers mentioned. Slaked lime has been used in coal tar pavements but to a very small extent in sheet-asphalt work and can not be classed as a desirable filler. Clay would probably make an excellent filler were it not for the extreme difficulty of keeping it from balling after drying and pulverizing it. Entire roads have been constructed of bituminous sand-clay mixtures which have given excellent satisfaction. Ground marl has also been used in some instances but it is very light and its use renders work on the mixing platform very trying, due to the dust produced. Much of the finer material blows away during the mixing process. Sand dust is undesirable, as it does not pack dry and its use makes the mixture very mushy and lacking in stability. Ground waste lime from beet sugar factories contains an undesirable proportion of organic matter. The weight of experience is decidedly in favor of the use of limestone dust for ordinary traffic conditions and Portland cement where the traffic is exceptionally heavy. In wet climates it is especially unwise to experiment with fillers that have not proven themselves satisfactory from long experience.

6. Binder Stone

As the binder course does not take any of the actual wear of traffic but serves as an intermediate course between the foundation and the wearing course, the selection of the materials used in it does not require the same care as must be applied to the selection of a sand. Almost any variety of good hard stone may be used. The maximum size of the stone should not exceed three-quarters of the thickness of the binder course to be laid with it. For instance, with a 1½-in binder course the stone should all pass a 1⅛-in screen; for a 1-in binder course it should all pass a ¾-in screen. The stone should not be weathered or soft and should preferably be free from all particles which will pass an 8-mesh sieve. This insures a stone free from dust, which is desirable because stone which contains a large amount of screenings segregates very badly in a pile and because in stone containing dust, more especially if it has been weathered, the dust appears to adhere to the larger particles to such an extent as to prevent the bitumen from properly adhering to them. The stone should be graded from coarse to fine with a preponderance of the larger particles. The voids between these should be filled with the next size particles, and so on, thus producing a compact rigid mass in which the voids are reduced to the smallest size compatible with the materials used. Extreme smallness of voids, such as is striven for in the wearing course is not essential or desirable in a binder course. Gravel has been used as a substitute for broken stone, but it is not to be recommended, as a binder course made with it lacks rigidity and stability and, generally speaking, bitumen does not adhere as well to gravel as it does to broken stone

7. Refined Asphalts

Refined asphalt usually forms the basis of the asphalt cement which binds together the particles of the mineral aggregate of a sheet-asphalt pavement. In the earlier days of the industry the refined asphalt was always of such a hard consistency that it was necessary to soften it by the addition of a flux. At the present time a considerable proportion of

the asphalt employed in paving work is refined to the proper consistency for use and requires no fluxing. The refined asphalt must possess such properties that when ready to be used in the pavement, either with or without the addition of a flux, it will firmly bind together the mineral particles and resist the disintegrating action of traffic and the elements. These necessary properties will be discussed at length under ASPHALT CEMENT and the individual characteristics of the different asphalts will be found in Sect. 12, BITUMINOUS MATERIALS. The primary source of asphalt of all kinds is undoubtedly petroleum. Some petroleums consist chiefly of what are termed asphaltic hydrocarbons and others contain these constituents in very small proportion. Only the former class are suitable for the production of asphalt and asphalts found in a hard state in nature are undoubtedly derived from them. The asphaltic hydrocarbons are of complex structure and consist largely of saturated and unsaturated cyclic and polycyclic compounds and their non-metallic derivatives. In many localities, thru natural causes, asphaltic petroleum has lost its more volatile constituents by condensation or evaporation, or both, and has left behind a more or less solid residue of asphalt. These residues have in some cases filled natural depressions, from which has arisen the term ASPHALT LAKES. The crude material, either solid or liquid, requires refining before it can be used. The water and light oils are driven off by heat and the residue is employed for paving purposes. In the case of some of the hard native asphalts as much as 30% of water must be removed, while with some of the asphaltic petroleums as high as 60% of light oils must be distilled before the residue is of the proper consistency. During the earlier stages of the industry great stress was laid on the merits of asphalts coming from certain deposits or localities, but, as the knowledge of the art of paving increased, the really essential qualities necessary for a paving asphalt were pretty definitely ascertained and methods for determining them became fairly well standardized. At the present time among those who are posted upon the subject, the source of an asphalt is not necessarily regarded as any index of its quality. It must in every case fully meet standard requirements. In this connection it must be borne in mind that different asphalts have their individual characteristics, which in many instances sharply differentiate them from all other asphalts and their efficiency for paving purposes is to a certain extent represented by the mean of their various physical and chemical properties. One asphalt may possess a certain quality to a much higher degree than another, but this does not necessarily mean that it is better for paving purposes, as the other asphalt may and probably will have its particular points of superiority also. No one asphalt can be said to be preeminently superior to all others in every respect. It is unwise to attempt to set a definite absolute minimum permissible standard for any one physical or chemical property because a certain asphalt might have its low standard in one particular respect offset by certain other high qualities. To apply this low standard without restriction to other asphalts which do not possess the offsetting qualities would be dangerous in the extreme. Because of this and because physical and chemical tests are not always absolutely conclusive in the present state of our knowledge, service tests are of great value in determining the fitness of an asphalt for paving purposes. A knowledge of the kind of crude material from which an asphalt is derived is extremely valuable because, when the asphalt is manufactured strictly in accordance with modern methods of refining from a particular crude material, it will possess

certain characteristics and a product from this crude which varies markedly from this standard should not be unreservedly accepted as fit for use until its worth has been proved. The argument that even in spite of such a departure from standard methods it is still superior in all respects to the minimum acceptable for all other kinds of asphalt should not be given weight for the reasons above stated. It has not been possible to define the effect of variations in any one physical quality in terms of increased requirements in other qualities. In all cases, therefore, the refining must be carried on with care and by the most approved methods in order to insure the production of an asphalt of good quality. The finished product is of varying degrees of purity, depending on the kind and source of the crude material and it is generally sold in wooden or iron barrels or in tank cars.

8. Fluxes

The fluxes now in use are the liquid residues left after distilling off the lighter products from petroleum. At first, residuums from paraffin base petroleums were used almost exclusively altho a few natural malthas were employed to a limited extent. Some of these fluxes contained as high as 30% of scale paraffin, tho the average was 8 to 12%, and asphalt cements made with them consisted of 25% of flux and only contained 65% of bitumen. The bitumen in these asphalt cements, therefore, contained from 3 to 9% of scale paraffin. Judging from the excellent service record of many of these pavements, the presence of this amount of scale paraffin in the bitumen could not have been detrimental, altho much has been said as to the harmfulness of this ingredient. Of late years the use of asphalts containing up to 5% of scale paraffin has become wide spread and their service records are excellent, so that the question of paraffin contents is no longer generally considered as of prime importance. Most natural malthas rapidly harden on heating and produce hard, pitch-like residues. Their use has therefore been abandoned. Residuums prepared from asphaltic and semiasphaltic petroleums are generally considered superior as fluxes to paraffin residuums, owing to their asphaltic nature. The bulk of the fluxes now employed are of this character. A flux to be suitable for use in the paving industry must be permanent in character and stable under heat. It must be a good solvent for the bitumen of the asphalt which is to be softened with it and must combine with it in such a manner as to produce an asphalt cement possessing the necessary properties. Unless a flux is free from light oils, these oils will evaporate in the pavement and soon leave the bitumen so hard that the pavement will crack. Unless they will stand exposure to the elements without being rapidly affected by them, a similar result will take place. They are mixed with the asphalt at temperatures from 149° C (300° F) to 177° C (350° F) and the asphalt cement so produced is sometimes kept at or near this temperature for several days. If they decompose or volatilize to any considerable extent under these conditions, asphalt cements made with them will harden rapidly in the melting kettles and require the addition of more flux and such a residuum would probably also harden rapidly in the pavement with the effect above described. Unless they are good solvents for bitumen they will not properly soften a hard asphalt and produce a homogeneous cement in which the hard bitumens are completely dissolved in the softer ones and this will result in a low cementing value of the asphalt cement. If the flux is a poor solvent for the bitumen, much

more care and time must be taken in the preparation of the asphalt cement to insure a complete solution. With limited kettle capacity this is a very important consideration. Certain fluxes are suited for use with certain asphalts and not with others. In some cases this is due to their solvent action, but this is not the only consideration. Certain asphalts are lacking to a greater or less extent in certain constituents and this lack can often be supplied by the use of a suitable flux. Other fluxes may be equally good solvents but may not contain sufficient of the lacking constituents and an asphalt cement made with them might be totally unsuitable, or at best of poor quality. An exhaustive examination of both asphalt and flux might be sufficient in some cases to determine this without a physical test, but chemical analyses do not always reveal physical defects and it is customary therefore to actually flux some of the asphalt to be used with the flux under examination and test the physical properties of the resulting asphalt cement. Because a certain flux gives good results with a certain asphalt is no criterion that it will be equally suitable for another kind of asphalt. Some fluxes of course are more universally suitable than others. In most cases an undue amount of cracking in the preparation of a residuum is undesirable as it is liable to produce unstable compounds in the residuum. Sometimes, however, this is not the case, as a certain amount of cracking may result in the formation of more stable compounds than those originally present, provided the light oils produced are removed by distillation. Desirable fluxes should all stand heating to 163° C (325° F), for 5 hr without losing more than 5% or becoming hard and should flash above 177° C (350° F) to insure safety in the plant. Flux is usually purchased in barrels or tank cars.

9. Asphalt Cements

Essential Characteristics. As previously indicated, this term is applied to the bituminous cementing material which is used to bind together the mineral particles entering into the composition of a sheet-asphalt pavement and is prepared either by refining liquid bitumen to the proper consistency or by mixing a hard asphalt with a suitable flux. However prepared, it is essential that it should possess certain properties in order to fit it for use in the asphalt paving industry. These may be discussed under the following heads: (1) Permanence when exposed to climatic and traffic conditions; (2) permanence when exposed to working temperatures in the manufacture of the pavement; (3) lack of undue susceptibility to changes in temperature; (4) purity; (5) cementing value; (6) ductility.

Permanence under Climatic, Traffic and Manufacturing Conditions. The coating of asphalt cement which is applied to each sand grain is necessarily very thin and great permanence is therefore required to enable it to resist the deteriorating influences of traffic and weather. Only those grains which are on the surface of the pavement are directly exposed to climatic influences and as they wear away the grains below form a new surface. If this wear is too rapid the pavement will not last as long as it should. Once the bitumen has lost its cementing power the grains become loose and are washed or swept or blown away, or ground out under traffic. Asphalt pavements are expected under normal conditions to give an average of 10 years of service and during summer time in a temperate climate often attain a temperature of 60° C (140° F) or over. In winter, a pavement often reaches a temperature below −18° C (0° F) and in many cases pavements are continually wet with no opportunity of drying out for

weeks at a time. During all these severe conditions they must successfully carry the traffic passing over them, so that the conditions affecting permanency are very severe indeed. The asphalt cement must resist the disintegrating and deteriorating effect of high and low temperatures and extreme wet, for on its ability to resist these influences depends the whole integrity of the pavement.

Non-Susceptibility to Changes in Temperature. When the same mineral aggregate is used pavements made with asphalt cements possessing different physical properties will vary very considerably. Some asphalt cements are much more affected by changes in temperature than are others; that is, become softer in summer and harder and more brittle in winter. Within limits, this tendency, more especially the softening in summer, may be counteracted by the more careful selection and grading of the mineral aggregate. The use of a sharper and better graded sand and an increase in the quantity of dust or filler will increase the stability of the mineral aggregate and render the pavement less soft in summer. Under the conditions ordinarily prevailing, asphalt cements which vary considerably in susceptibility to changes in temperature may be successfully employed. In certain localities, however, it is impossible to secure sands of the best type, as previously noted under sands, and under these conditions it may be necessary to limit the susceptibility to changes in temperature of the asphalt cement used.

Purity is essential up to the point where it is possible to use the asphalt cement as a cementing material. A mixture containing only 25% of bitumen could hardly be regarded as an asphalt cement. Excessive quantities of mineral matter would make it very difficult to melt such an asphalt cement and keep it in such a state of agitation that it would have a uniform bitumen content. Undesirable impurities which would tend to rot or disintegrate the pavement should also be excluded.

Cementing Value. The chief, if not the only, function of the asphalt cement in a pavement is to bind the particles of the mineral aggregate together so that it will sustain the traffic. It is essential, therefore, that it should possess cementing value to a very high degree. From a theoretical standpoint the degree required would depend upon the service conditions. Where the sand is properly graded and the grains are thus brought together in close contact, it is perhaps fair to assume that less cementing value is required than when the grading is poor. Similarly an asphalt cement which is low in cementing value might be successfully employed on light traffic streets altho it would fail under heavy traffic. Certain sands are much more difficult to coat than are others and in such cases a very high degree of cementing value in the asphalt cement is absolutely essential. From the practical standpoint, however, the severity of the conditions met with in service makes it extremely dangerous to set up anything but a very high standard for the cementing value of all asphalt cements used in paving work. A light traffic street of to-day may become a heavy traffic street of to-morrow and the science and art of paving has not reached that stage where it is possible to prescribe definite cementing values for certain conditions.

Ductility. Pavements are frequently subjected to very rapid and great changes in temperature, which inevitably produce expansion and contraction. Unless the asphalt cement possesses sufficient ductility, this will result in the cracking of the pavement and for this reason ductility is considered as one of the necessary qualities of an asphalt cement. When

the pavement is subjected to a considerable amount of traffic, the stresses set up by contraction and expansion are equalized to a considerable extent and for this reason pavements on light traffic streets are more liable to crack than are pavements on streets carrying heavy traffic.

10. Theory of Sheet-Asphalt Pavements

Broadly speaking, the governing principles are: (1) The selection of a mineral aggregate of sufficient hardness and denseness to resist the abrasive action of traffic; (2) binding the various particles of the mineral aggregate together in such a way that the pavement will maintain a smooth surface and resist the disintegrating action of traffic and the elements.

General Functions of Sand, Filler and Asphalt Cement. Relative cheapness of the various ingredients is of course essential. It is probably correct to assume that sand is the last and most permanent stage of the mineral ingredients of the earth's crust and sooner or later all rocks when exposed to weather become reduced to the state of sand. If the sand particles were bound together with a rigid cementing material it would make a hard unyielding pavement and a more or less noisy one and expansion and contraction would play a large part in its disintegration. By using a non-rigid bituminous cement many of these disadvantages are overcome. As the bituminous cement, however, becomes soft in summer the requisite stability of the pavement in hot weather must be secured by proper grading of the sand and mixing it with a sufficient quantity of finely ground mineral filler so that the voids between the mineral particles shall be reduced to the smallest practicable size. The consistency of the bituminous cementing material must be such that it will not be too brittle in winter or too soft in summer and it must adhere tenaciously to the grains, bind them together firmly and resist traffic and weathering. These broad general principles were far from being well understood at the commencement of the industry. At that time sand was sand and the function of the filler was not clearly recognized and what constituted a good asphalt or a bad asphalt was largely a matter of advertising and clever promotion work. The two factors influencing the design of a sheet-asphalt pavement to meet specific requirements are traffic and climatic conditions and these affect both the mineral and bituminous ingredients. Where the traffic is dense and consists largely of slow moving, heavily loaded, iron-tired vehicles, it is evident that the crushing strain on the individual sand grains will be very great. Where a sand grain is crushed it leaves a depression in the pavement in which water can collect and where a large number of these grains are crushed this has a very serious effect upon the life of the pavement, more especially in wet climates. For very heavy traffic of this kind it is, therefore, essential that the proportion of 10 and 20-mesh grains should be very small and in pavements laid in Glasgow, Scotland, where the climate is very wet and the traffic was extremely heavy practically no grains coarser than 40-mesh were employed. This produced a pavement which in very hot weather would have been somewhat lacking in stability, but as the summer temperatures in Glasgow are comparatively low, this was not a serious defect. The stability of the mineral aggregate is greatly increased by the presence of 10 and 20-mesh grains and where they are absent this must be compensated for by the use of a filler which gives the maximum stability and if necessary by the use of a slightly harder asphalt cement.

Sheet-Asphalt in Dry and Wet Climates. In very wet climates, espe-

cially when the traffic is heavy, the coating of bitumen on the sand grains must be thicker than is required under drier conditions and the temperature at which the ingredients are mixed, as well as the duration of the mixing process should be increased in order to insure the maximum adherence of the bituminous coating to the sand grains. The difference between wet and dry conditions on a sheet-asphalt pavement in which the grains were thinly coated with bitumen is clearly shown by a test at the National Physical Laboratory, at Teddington, England, in the winter of 1914–1915. This test was conducted by The Road Board of Great Britain on its specially designed road machine. In this machine iron-tired wheels, each provided with its own motive power and which can be loaded to any desired extent, pass over the surface of the test pavement which is laid on the concrete foundation of a circular track. The same mixture had been laid on a considerable area of roads in the immediate vicinity of Teddington, and during the dry weather immediately following their construction, gave excellent satisfaction. This was followed by a period of unprecedently wet weather during which the roads broke up very badly and it was then decided to test the mixture in the road machine. The mixture which had failed was accordingly duplicated, using the same materials, machinery and men and laid on the track of the testing machine. Analyses of the old and new mixtures showed them to be substantially identical. The test pavement analyzed as given in column A.

	A	B
Bitumen	8.9%	11.6%
Passing 200-mesh sieve	7.0%	14.7%
Passing 100-mesh sieve	9.2%	8.4%
Passing 80-mesh sieve	15.6%	10.0%
Passing 50-mesh sieve	37.0%	28.3%
Passing 40-mesh sieve	12.0%	13.4%
Passing 30-mesh sieve	6.6%	7.8%
Passing 20-mesh sieve	2.5%	3.4%
Passing 10-mesh sieve	1.2%	2.4%
	100.0%	100.0%

Under a dry test this pavement lasted for weeks and showed no signs of undue wear. The test was then conducted under the same conditions except that the surface of the pavement was kept continually wet and it then broke up so badly that the machine had to be stopped within a few hours from the time that the wet test commenced. In order to prove that the materials used were not at fault, a mixture using the same machinery, men, sand and bitumen was made and tested in the road machine. Owing to the limitations imposed by the conditions of test, the grading could not be greatly improved but the quantity of filler and asphalt cement was increased. This mixture analyzed as given in column B, and stood, without breaking up, the test given in the table on following page. For purposes of comparison it should be stated that the best test which any mixture has ever given under similar conditions on this machine, which was purposely designed to test pavements to destruction in a comparatively limited time, was: Dry test, 11 hr, 27 min; wet test, 96 hr.

Dry Test

Duration	Total Load per Wheel	Speed of Wheels
75 min	3 cwt	1 mile per hr
120 min	6½ cwt	1 mile per hr
165 min	10 cwt	1 mile per hr
120 min	12½ cwt	1 mile per hr
100 min	15 cwt	1 mile per hr
107 min	20 cwt	1 mile per hr
11 hr 27 min	11.3 cwt average load	1 mile per hr

Wet Test

Duration	Total Load per Wheel	Speed of Wheels
50 hr	12½ cwt	6 miles per hr

Sand Grading and Bitumen Content. Under light traffic a sand containing a comparatively large proportion of coarse grains is desirable for several reasons. The finer the grains the greater the surface area to be covered with bitumen. This can be readily understood from a consideration of the following: A 1 ft cube has six sides each 1 sq ft in area. Cut it in two and there are eight sides of the same area and each time it is cut new surfaces are created. Of two pavements each having the same bitumen content, the one containing the larger proportion of coarse grains will therefore have the thicker coating of bitumen on the grains, owing to the smaller surface area which the given quantity of bitumen has to cover. The kneading action of traffic upon a pavement tends to equalize the stresses set up by contraction and expansion and to keep the life in the bitumen. Where the traffic is very light, all asphalt pavements have a tendency to crack for the above reasons and, other things being equal, those in which the grains are thinly coated with bitumen crack first. Increasing the amount of bitumen in a fine grained heavy traffic mixture would tend to remedy this, but too much bitumen would render it sloppy, and it would be much more expensive to lay than the coarser mixture carrying a lower percentage of bitumen and the coarser mixture would carry the light traffic just as well. The sand gradings which have been found to give the best results in practice for stability and wear are given elsewhere under sand, as well as the effect of rounded grains and different surfaced grains. With the standard grading the normal bitumen content of pavements in the United States varies from 10.5 to 12% and except under special conditions this gives satisfactory results. In England, where the climate is much wetter and the extremes of temperature not so great, the percentage of bitumen varies from 11 to 13. Where, on account of excessive moisture, the bitumen must be increased and the variations in temperature are great, Portland cement is perhaps the best filler to use, as it increases the stability of the mineral aggregate to a marked extent. It is also advisable to increase the amount of filler used up to a maximum of 20% of 200-mesh filler in the mixture.

Asphalt Cement. On a very heavy traffic street the stability of the mixture as well as the cementing strength of the bitumen is increased by

hardening the asphalt cement. The average penetration of all asphalt cements used in sheet-asphalt pavements laid at the present time in the United States lies somewhere between 50 and 60, but on very heavy traffic streets, even in fairly cold climates, as low as 20 has been successfully used. On a light traffic street a pavement laid with a 20 penetration asphalt cement would inevitably crack badly but under heavy traffic the contraction stresses are equalized almost as soon as they are set up and hence cracking does not take place. For normal traffic it is desirable to use as soft an asphalt cement as possible to offset the hardening effect of time on all bituminous cements. To do this successfully requires that especial attention be given to the stability of the mineral aggregate. This stability is governed by three main factors: (1) Grading of mineral aggregate; (2) shape of sand grains; (3) kind and amount of filler used.

Grading of Mineral Aggregate. In an ordinary sand mixture a certain proportion of 10, 20 and 30-mesh grains add greatly to stability and the 10-mesh particles add relatively more than do the 20 and 30-mesh particles. Provided the balance of the grading and the shape of the grains are satisfactory, a mixture containing 5, 8 and 10% of 10, 20 and 30-mesh grains respectively, will have the requisite stability. Increasing the percentage of these size grains up to a reasonable amount will, under the conditions stated, increase the stability, but when the traffic is heavy, this is objectionable for the reasons previously given. Where larger sized particles are used, as in binder, care must be taken not to use enough fine material, such as sand, to force the larger particles apart, as this will reduce the stability of the mixture. In binder the maximum stability is secured by permitting the large particles of stone to interlock as closely as possible and filling up the spaces between them with just enough sand to reduce the size of the voids. In this way the stones are held more firmly in place by increasing the contact area of the bitumen coated particles. Where stone alone is used, more especially if it is not well graded, but comparatively few parts of any one particle are in contact with other particles and the effective cementing action of the bituminous cement is therefore reduced to the minimum. Where the mixture contains 10 to 20% of particles passing a ½-in screen and retained on a ¼-in screen, the balance being made up of particles passing a 10-mesh sieve, a very slight excess of bitumen renders it very unstable. In such a mixture the larger grains are forced apart by an excess of fine material and they are sufficiently large to allow traffic passing over them to exert a leverage action upon them tending to displacement of the pavement. This is not the case with 10, 20 and 30-mesh grains. Beyond a certain size, therefore, the addition of coarse material does not tend to increase stability unless it is carried to the point where the coarser grains are permitted to interlock to the maximum extent possible.

Shape of Sand Grains and Kind, and Amount of Filler. Grains which are comparatively round, and therefore move upon each other readily, are much less stable than angular grains. The increased stability obtained by the addition of finely ground filler to a sand can readily be observed by mixing filler with sand in varying proportions and consolidating the dry mixture by successively placing small amounts of it in a cylindrical vessel from 1 to 2 in in diameter and 10 to 12 in high and consolidating it by tapping. Care should be taken to avoid segregation. After a sufficient amount of filler has been added, it will be possible to turn the cylinder upside down without any of the mixture running out. In other words

it will pack dry. Up to a certain point the ability to pack dry will increase with an increased proportion of filler. Beyond that point, which varies with different sands, it will apparently decrease until the point is reached where the mixture consists very largely of filler, when it will again increase. For this reason mixtures composed almost wholly of 100 and 200-mesh angular particles, such as are found in French, Italian and German rock asphalt pavements, are exceedingly stable. There is not much apparent difference between dry mixtures made up of the same sands using limestone and Portland cement fillers respectively of the same degree of fineness. When the bitumen is added to the mixture, however, the one in which Portland cement was used will be considerably stiffer to rake and will possess the greater stability. The cause for this is not clearly understood, but it evidently can not be due to any setting action of the Portland cement, as the grains are all covered with asphalt cement, thus excluding moisture from them and the effect is noticeable as soon as the hot mixture is made or dumped upon the street. The filler is almost always added cold to the hot sand just before it is mixed with the asphalt cement. If it were added to the cold sand and fed with it to the drying drum, much of the filler would be carried off as dust by the draught, besides which the limestone might be decomposed by the heat and segregation would inevitably take place in the hot sand bin. The different batches would consequently vary very greatly in mesh composition. The maximum amount of cold filler which can be added to a mixture obviously depends upon the ability of the hot sand to bring the mixture of sand and cold filler up to the proper temperature for mixing it with asphalt cement. Too much filler would chill the sand to an undesirable extent. It would also increase the amount of bitumen required by the mixture and beyond a certain point might render it sloppy. For these reasons the amount of filler added rarely exceeds, under normal conditions, 18% of the mixture. Some asphalts, such as Trinidad and Mariel (Cuban), contain a large proportion of finely divided mineral matter which acts as a filler in the mixture and this reduces the amount of filler necessary to add when such asphalt cements are used. Amorphous and colloidal fillers, such as clay, absorb the bitumen with which they are coated and their particles therefore retain the coating much more tenaciously than do crystalline and non-absorbent particles. This is undoubtedly one of the reasons why the use of clay as a filler is indicated from a theoretical standpoint. For the same reasons mixtures made with a limestone filler resist water action much more strongly than mixtures made with a ground silica filler. When determining the amount of filler to be added to a mixture consideration must be given to: (1) Traffic and climatic conditions; (2) kind and grading of sand; (3) mesh composition of filler; (4) mineral contents of asphalt cement. In very wet climates more filler should be used than is necessary under drier conditions in order to make a mixture in which the voids are of minimum size, thus preventing water from entering the pavement. Under these conditions the percentage of 200-mesh filler in a mixture may be carried as high as 20%. Under favorable climatic conditions, with light traffic and good sands, the 200-mesh material in the mixture may vary from 8 to 12%. Under heavy traffic the limits may be considered as lying between 10 and 15%. As previously noted, 200-mesh sand is undesirable in a pavement, as it tends to make a mushy mixture and should not be regarded as a filler. Where a sand of suitable mesh composition, as described under SAND, contains practically the same amount of 100 and 80-

mesh grains, more filler can be added to it in certain cases than if the proportion of 80-mesh grains was low. Mixtures deficient in 100 and 80-mesh grains, especially the latter, are liable to ball up and rake with extreme difficulty if the normal amount of filler be added to them. The true remedy of course is to secure sand with a proper amount of 80-mesh material in them. If this is impossible, it is better to use an asphalt cement which is extremely fluid at ordinary working temperatures, such as California asphalt, rather than to reduce the amount of filler used below the generally established limits. Generally speaking, sands of rather unsatisfactory mesh composition and having rounded grains require more filler than do sands of more suitable character. With sands of this character it is desirable to use an asphalt cement which does not readily become fluid on the application of heat.

Determination of Amount of Filler and Bitumen. It is of course always necessary to determine what percentage of filler will pass a 200-mesh sieve. If a mixture is desired containing 15% of 200-mesh material derived from the filler alone, and the filler contains 75% of 200-mesh material, it will be necessary to use 20% (15% ÷ 75%) of the filler in the mixture. The mineral contents of an asphalt cement will of course depend upon the composition of the refined asphalt used in it. Let it be assumed that the refined asphalt to be used contains 60% of bitumen and that the balance is finely divided mineral matter which can properly be regarded as a filler. Assume further that 20 lb of flux per 100 lb of refined asphalt is to be used in the preparation of the asphalt cement and that this asphalt cement will be kept continuously and thoroly agitated. Its mineral and bitumen contents would be determined by the following calculation: 100 lb refined asphalt containing 60% bitumen = 60 lb pure bitumen; 20 lb flux containing 100% bitumen = 20 lb pure bitumen. Hence, 120 lb asphalt cement will contain 80 lb pure bitumen, equivalent to 66.6% of bitumen. The balance, 33.3%, in this case is all mineral matter which was assumed to be a satisfactory filler. If the mixture is to contain 11% of bitumen, 16.5% (11% ÷ 66.6%) of this asphalt cement must be added to it. From the asphalt cement, therefore the mixture would derive 5.5% (16.5 − 11) of filler and if a total of 10% were desired, only sufficient filler must be added to insure the presence of 4.5% (10 − 5.5) more. If the filler contains 75% of 200-mesh material, this would require 6% (4.5% ÷ 75%) of filler to be added to the mixture. The proper amount of bitumen to add to a mixture is not always possible to determine in advance. With a normal sand and standard grading it usually varies from 10.5 to 11.5% in the United States. As previously explained, it is a function of the surface area of the grains to be covered taken in connection with the thickness of the coating desired to meet the conditions involved. Generally speaking, a mixture in which the grains are sufficiently covered will produce a stain on manila paper if the hot mixture is placed on it, the paper folded over and a smart blow given to it. The hotter the temperature of the mixture the deeper the stain. Bitumens which are very liquid at 149° C (300° F) will give deeper stains than those which are less liquid, so that a certain amount of skill and experience is necessary before the results of the pat test can be correctly interpreted. Once this is acquired, the pat test is a most valuable one for use with normal mixtures. Where the conditions call for an excessively rich mixture the test is of no use, as the paper is stained so heavily that no conclusions can be drawn from it. It frequently happens that two sands may have exactly the same mesh composition and yet one will require 2 or 3% more

bitumen than the other. Preliminary examination of the sand will not always reveal this, but the pat test will invariably demonstrate it conclusively. It is also generally, but not so positively, indicated by the appearance and working of the mixture. Certain sands with rounded grains will not take as much as 10.5% of bitumen without making a mixture which is undesirably sloppy. To the trained eye, the working of the mixture on the street will usually suggest what changes should be made in it, and this has been discussed at length under methods of laying. As all batches of surface mixture are based on a definite weight of sand, it is customary to give the plant foreman a formula based on 100 lb of sand. If the plant used measures the sand instead of weighing it, the volume of the sand box must be ascertained as well as the weight of a cubic foot of the dry hot sand which is to be employed. A simple calculation will then give the number of pounds of sand per batch. Assume that the sand and filler have been examined and that the asphalt cement has been determined as shown above, or by actual analysis, to contain 66.6% of bitumen. Also assume that it has been decided to add 15 lb of filler to every 100 lb of sand and that the finished mixture is to contain 11% of bitumen. The number of pounds of bitumen to add to the above mixture of sand and filler can readily be calculated as follows: a = lb of sand and filler = 115; b = percent bitumen in asphalt cement = 66.6%; c = percent bitumen desired in pavement = 11.0%. Then

$$\frac{a \times c}{b - c} = \frac{115 \times .11}{.666 - .11} = \frac{12.65}{.556} = 22.75 \text{ lb}$$

Hence the formula will be: Sand, 100 lb; dust, 15 lb; asphalt cement, 22.75 lb. If the contents of the sand box were found to weigh, for example, 850 lb, all the figures in the above formula would require to be multiplied by 8.5 (850 ÷ 100).

In connection with the foregoing discussion, the following table showing the composition of pavements laid in various cities of the United States and Great Britain may prove of interest.

The English mixtures are typical heavy traffic mixtures for wet climates. The Seattle mixture is for medium traffic and a wet climate. The poor Ottawa mixture cracked very badly while the one designated as good has given very satisfactory service. The poor Montreal mixture also cracked very badly. The balance of the mixtures are for medium to heavy traffic and normal rainfall with the exception of the old Washington, D. C., mixture, which, while very unorthodox, gave good results under very light traffic and the New Brunswick mixture, which may be regarded as a typical light traffic mixture.

11. Inspection and Sampling of Materials

Broadly speaking, a comprehensive system of inspection of bituminous materials and pavements or roadways made from them may be subdivided as follows: (1) Preliminary inspection of raw materials; (2) inspection of materials and processes during construction work; (3) inspection of finished work.

Preliminary Inspection of Raw Materials. These are, or should be, assembled by the contractor sufficiently in advance of starting the work to permit of their being tested. They usually consist of refined asphalt or asphalt cement; residuum flux; crushed stone or gravel; sand; and filler. All of these materials should be sampled from deliveries actually on hand on the work. Except where the manufacture of the material

Table I.—Composition of Different Sheet-Asphalt Pavements

City	Bitumen	Passing 200	Passing 100	Passing 80	Passing 50	Passing 40	Passing 30	Passing 20	Passing 10	Ret'd on 10
	12.5%	8.5%	12.0%	27.0%	34.0%	8.0%	1.0%	1.0%	1.0%	.....
	12.7%	15.8%	13.8%	25.9%	30.0%	1.9%	0.1%	0.2%		.....
	11.5%	16.1%	16.1%	17.5%	32.2%	3.6%	0.5%	0.2%	0.1%	.....
y.	10.8%	13.2%	12.0%	11.0%	24.0%	11.0%	8.0%	6.0%	4.0%	.....
	10.5%	12.5%	14.0%	15.0%	35.0%	6.0%	4.0%	2.0%	1.0%	.....
	11.2%	11.8%	10.0%	10.0%	41.0%	10.0%	3.0%	2.0%	1.0%	.....
	10.8%	12.7%	15.0%	17.0%	22.0%	10.0%	5.0%	4.0%	4.0%	.....
	11.8%	11.7%	11.0%	16.0%	36.0%	8.0%	2.0%	2.0%	2.0%	.....
	12.6%	14.9%	17.5%	9.3%	22.8%	5.6%	7.0%	4.9%	5.4%	.....
	11.8%	10.2%	12.0%	11.0%	23.0%	11.0%	9.0%	7.0%	5.0%	.....
	10.5%	10.2%	12.9%	9.9%	21.6%	16.6%	6.2%	7.1%	6.0%	.....
	10.1%	10.9%	10.0%	11.0%	48.0%	6.0%	2.0%	2.0%	1.0%	.....
	10.6%	14.4%	12.0%	14.0%	24.0%	17.0%	6.0%	1.0%	1.0%	....
	10.9%	10.1%	20.0%	12.0%	33.0%	8.0%	4.0%	1.0%	1.0%	.....
	11.0%	10.0%	10.0%	8.0%	25.0%	11.0%	10.0%	8.0%	7.0%	.....
xtures	9.6%	8.4%	4.0%	5.0%	22.0%	17.0%	16.0%	10.0%	8.0%	.....
	11.0%	10.0%	16.0%	5.0%	14.0%	14.0%	14.0%	10.0%	5.0%	1.0%
	10.2%	9.8%	11.0%	13.0%	7.0%	15.0%	10.0%	6.0%	1.0%	.....
	11.0%	13.0%	10.0%	9.0%	26.0%	7.0%	11.0%	7.0%	6.0%	.....
	11.0%	11.0%	10.0%	18.0%	23.0%	2.0%	16.0%	6.0%	4.0%	.....
	11.6%	13.4%	17.5%	9.5%	28.0%	5.5%	7.5%	4.5%	2.5%	.....
	7.8%	8.2%	12.5%	9.0%	26.0%	9.5%	11.5%	10.5%	7.5%	2.5%
	11.2%	10.8%	6.0%	10.0%	34.0%	5.0%	10.0%	5.0%	4.0%	4.0%
	9.4%	4.6%	6.0%	6.0%	35.0%	10.0%	16.0%	10.0%	4.0%	....
	10.5%	9.5%	9.0%	8.0%	22.0%	13.0%	12.0%	9.0%	7.0%	.....

is inspected at the refinery, this rule should never be departed from in the case of the bituminous materials themselves; that is, the refined asphalt or asphalt cement and the residuum flux. In the case of the materials which constitute the mineral aggregate of the pavement or roadway, contractors are often unable to judge themselves whether or not a particular material passes the requirements of the specifications and before placing their order for them they frequently submit samples obtained from different dealers for approval. In the case of crushed stone or gravel, these samples usually fairly represent the kind of material which will be delivered. This is also true in the case of filler. With sands, however, samples submitted by the dealers frequently vary very greatly from actual deliveries. It often happens that the selection of sand has not been given sufficient attention or has been deferred until the last moment, with the result that no really suitable samples are submitted. In such cases it is frequently to the interest of all parties concerned, altho perhaps not strictly the duty of the inspector, to personally visit and examine available sources of sand in the immediate neighborhood. In this way much better material may often be obtained than would otherwise be the case.

Sand and gravel banks are usually stratified and where the deposit has been made from comparatively still water the lower strata will usually contain coarser material than the upper strata. In every case the sand dealer should be impressed with the necessity of carefully stripping the top of the bank to remove deposits of clay, loam, etc, as this material is undesirable and will usually ball up in the heating drums. Where the strata vary considerably and can not be dug separately, it will be necessary to take an average sample of the run of the face of the bank in order to determine what will be the composition and character of the average output of the deposit. In certain cases it is necessary to select definite strata and have all the sand taken from them. In other cases the sand is dredged from river or creek beds and in order to obtain a satisfactory supply it is sometimes necessary to go on board a dredge with a set of screens and a sand scale and sample the sand obtained from various portions of the river-bed. When prospecting outlying country for available sand deposits, a small frying pan is a very convenient utensil to carry, together with the sand sieves and scales. By means of it, samples of sand taken from various pits can be dried over a small fire and sifted on the spot, which avoids the necessity of carefully marking them for identification and taking a lot of samples back to the laboratory or office. When securing samples of materials for examination, these should be carefully selected so that they really represent an average of the materials. The quantities necessary for examination are about as follows: Refined asphalt or asphalt cement, 1 lb; residuum flux, ½ to 1 quart; crushed stone or gravel, 1 to 3 lb; sand, 1 lb; filler, ½ lb. When these are sent to a central testing laboratory they should be plainly marked with the following information: Kind of material; date material was received at paving yard; date when sample was sent; quantity of material represented by sample; name of manufacturer or from whom purchased; name of paving contractor who is to use the material represented by the samples; name of city or town in which work is being done.

Method of Obtaining Samples. Refined Asphalt. This is usually shipped in barrels containing from 300 to 500 lb each. It will depend on circumstances and the quantity of material on hand how many barrels should be examined. Where the barrels are marked with the dates or batch

numbers and different batches are represented, it will usually be sufficient to take a single sample from each batch. Certain specifications give a permissible limit of variation in the penetration or consistency of different shipments of asphalt. In such cases it will be necessary to test for penetration a sample from each batch number, in which case all of the samples taken must be kept separate. Where no such provision is included in the specifications and the inspector is assured from his past experience that the particular manufacturer from whom the material was purchased is careful in his output, a fewer number of samples will be necessary than under other circumstances. In some cases an average sample made up of different samples taken from the requisite number of barrels will be all that is required. The packages or barrels used by different manufacturers are very often characteristic of the product, and this is also true of the odor and general appearance of the material. A qualified inspector will often be able to determine from observation whether or not the contractor's statement as to the source of the material which he intends to use is correct. In taking the samples, material should be selected which is free from dirt, etc, and which has not been exposed to the air. In other words, a piece of refined asphalt should not be taken from the top or immediately adjacent to the outside of the barrel.

Asphalt Cement. This is quite often shipped in tank cars and in such cases a single sample taken, preferably after the contents of the car have been melted, will be sufficient.

Crushed Stone or Gravel. Various samples from different portions of the pile should be taken and mixed together, and from the mixed portion sufficient should be selected for test. It is always advisable to dig into the surface of the pile a little way in order to get material which has not been exposed to the atmosphere and which possibly has lost thru the action of wind or rain, or both, a considerable portion of its fine material.

Sand. It is almost impossible to secure a fairly representative sample of dry sand, as the coarser grains have a different angle of flow from the finer grains and are found in different portions of the pile. The pile should always therefore be dug into some distance below the surface until damp sand is reached. After sampling the pile in this way in a number of places, the samples so obtained should be mixed together and sufficient taken for test from the mixed lot.

Filler. This is usually Portland cement or finely ground limestone dust, and comes in bags. No particular difficulty attends the sampling of this material, but a sufficient number of bags should be opened and samples obtained from them and mixed together in order that the sample sent for test shall correctly represent the average quality of the material.

The examination of the samples so obtained is usually conducted in accordance with detailed specifications. As these vary somewhat in their requirements, it is impossible to lay down a general rule which will cover the examination of raw materials for paving work. After the materials have been examined in the laboratory and found to be suitable for the work and in accordance with the specifications, the inspector can frequently be of great service in suggesting to the contractor the best formula to use. All paving specifications allow considerable leeway as to the composition of the mineral aggregate and the percentage of bitumen required in the mixture. Sometimes the decision lies entirely with the engineer on the work and where he is fully competent to decide these questions it should, of course, be left to him. As the contractor usually has to assume a guar-

antee on the completed work, he naturally feels that he should be consulted as to the formula used. Sometimes his desire to reduce the cost of his work will lead him to employ a formula which, while complying with the minimum requirements of the specifications, is really not suited to the work in hand. Whenever possible, cooperation between the inspector and the contractor will always secure the best results and a little tact used in this connection will usually be all that is required. It frequently happens that two or more kinds of sand or stone have to be mixed together in order to secure a suitable mineral aggregate. Many contractors are exceedingly careless in keeping their different kinds of materials separated. Unless this is done it is impossible to make a uniform mixture of the various materials and provision for the piling in separate and convenient places of the different materials should always be made before they are delivered. This is a very important consideration and lack of attention to it will not only hamper the execution of the work but impair its quality as well. It is necessary and advisable to impress on all the dealers furnishing raw materials the necessity of a uniform supply. This is particularly the case with sand dealers, who are often small men who have been accustomed to supply sand to builders and parties requiring it in small amounts. Almost invariably, men of this type will not realize the great difference which a, to them, small variation in the mesh composition of the sand will make to the paving contractor.

12. Specifications for Materials

The following specifications for materials used in sheet-asphalt pavements were adopted in 1916 by the Am. Soc. Mun. Imp. At the conclusion of the specifications comments and explanations pertaining to several sections of the specifications have been appended.

"2. The materials used must comply with the requirements of these specifications and be suitable for use upon the street or streets to be paved. They shall be mixed in definite proportions by weight, depending upon their character, and the traffic upon the street, and such materials and proportions must be satisfactory to the Engineer.

"3. **Methods of Testing.** All tests herein specified must be conducted according to official methods on file in the office of the Engineer. All penetrations at 25° C (77° F) are expressed in hundredths of a centimeter and are to be taken, except where otherwise specified, with a No. 2 needle acting for 5 sec without appreciable friction under a total weight of 100 g.

"4. **Refined Asphalts.** The refined asphalts admitted under these specifications shall be prepared from a natural mineral bitumen, either solid or liquid, or from combinations thereof, by such methods of refining as will produce a product complying with the requirements hereinafter given.

"The preparation and refining of all asphalts admitted under these specifications shall be subject to such inspection at the paving plants and refineries as the Engineer may direct. Every refined asphalt admitted under these specifications, if required by the Engineer, shall be equal in quality to the recognized standard for its particular kind or type of asphalt. If desired, the Contractor may use an asphalt cement prepared at the refinery. To be acceptable this asphalt cement must comply with the foregoing general requirements for refined asphalt, as well as requirements a, b, c, d, and e for asphalt cement.

"Asphalt obtained by the refining of natural liquid bitumens shall not be reduced in the refining process to a penetration at 25° C (77° F) of less than 30.

"All refined asphalts admitted under these specifications must comply with the following requirements.

a. All shipments of refined asphalt of any one kind shall have the batch number plainly marked on each package or container and shall be uniform in consistency

and composition and shall not vary from maximum to minimum more than 15 points in penetration at 25° C (77° F).

b. Ninety-eight and one-half per cent of the total bitumen of all refined asphalts shall be soluble in carbon tetrachloride.

c. When made into an asphalt cement by the use of such materials and methods as are described in these specifications, they must produce an asphalt cement complying with all the requirements elsewhere set forth herein for asphalt cements.

"5. **Fluxes.** These shall be the residues obtained by the distillation of paraffin, asphaltic, or semiasphaltic petroleums. They shall be of such character that they will combine with the asphalt to be used to form an acceptable and approved asphalt cement complying with the requirements of these specifications. All residuums must pass the following general tests:

a. They must have a penetration greater than 350 with a No. 2 needle at 25° C (77° F) under a 50 g weight for 1 sec.

b. They shall have a specific gravity at 25° C (77° F) between 0.92 and 1.02.

c. When 20 g of the flux is heated for 5 hr at 163° C (325° F) in a tin box, 2¼ in in diameter and ¾ in deep, after the manner officially prescribed, the loss shall not exceed 5% by weight and the residue left after such heating shall flow at 25° C (77° F).

d. They shall not flash below 177° C (350° F) when tested in a closed oil tester.

e. They shall be soluble in carbon tetrachloride to the extent of not less than 99%.

"6. **Binder Stone.** This shall be clean, hard, broken stone, free from any particles that have been weathered, or are soft. If the stone does not contain the proper amount of material passing the ½-in screen, the deficiency may be made up by the addition of gravel or sand. Ninety-five percent of the binder aggregate shall pass a screen having circular openings whose diameter shall be three-fourths the thickness of the binder course to be laid. The remaining 5% shall not exceed in their largest dimension the thickness of the binder course to be laid. The binder aggregate shall be so graded from coarse to fine as to have the following mesh composition, sieves to be used in the order named:

Passing		Total passing
10-mesh	15 to 35%	½-in.....35 to 85%
½-in circular opening and retained on 10-mesh	20 to 50%	

"The above limits as to mesh composition are intended to provide for such permissible variations as may be rendered necessary by the available sources of supply and the character of the work to be done. The mesh composition and character of the stone may be varied, within the limits above specified, at the discretion of the Engineer, depending upon the kind of asphalt used and the traffic conditions upon the street or streets to be paved.

"7. **Sand.** The sand shall be hard, clean grained and moderately sharp. On sifting it shall have the following mesh composition, sieves to be used in the order named:

Passing		
200-mesh	0 to 5%	
100-mesh and retained on 200-mesh	10 to 25%	Total passing 80-mesh and retained on 200-mesh............20 to 40%
80-mesh and retained on 100-mesh	6 to 20%	
50-mesh and retained on 80-mesh	5 to 40%	
40-mesh and retained on 50-mesh	5 to 30%	
30-mesh and retained on 40-mesh	5 to 25%	Total passing 10-mesh and retained on 40-mesh............12 to 45%
20-mesh and retained on 30-mesh	5 to 15%	
10-mesh and retained on 20-mesh	2 to 10%	
8-mesh and retained on 10-mesh	0 to 5%	

"On very light traffic streets a coarser sand may be used with the approval of the Engineer, but in no case shall a sand be employed that contains less than a total of 15% passing an 80-mesh sieve, such total to contain not more than 5%, calculated on the original sand, passing a 200-mesh sieve, or a mixture of 75% of sand of the character above specified and 25% of stone screenings passing a ¼-in screen and retained on a 10-mesh sieve may be employed.

"The above limits as to mesh composition are intended to provide for such permissible variations as may be rendered necessary by the available sources of supply. and the character of the work to be done, it being understood that the coarser permissible grading is intended for use on light and medium traffic streets only, and that

for heavy traffic streets, the finer grading shall be required. The mesh composition and character of the sand shall be varied, within the limits above specified by the Engineer depending upon the kind of asphalt used and the traffic conditions upon the street or streets to be paved.

"**Filler.** This shall be thoroly dry limestone dust or Portland cement, the whole of which shall pass a 30-mesh sieve and at least 66% of which shall pass a 200-mesh sieve. The surface mixture shall contain from 6 to 20% of this filler, depending upon the kind of sand and asphalt used and the traffic conditions upon the street or streets to be paved.

"**8. Samples.** One pound samples of the refined asphalt, petroleum flux and asphalt cement that the Contractor proposes to use in his work, together with a statement as to the source, character and proportions of the materials composing them, must be handed in with his bid and no contract shall be awarded to any bidder whose samples do not comply in every respect with these specifications. No asphalt other than that specified in his bid shall be used by any Contractor except with the written consent of the Engineer and provided that it complies in all respects with the requirements of these specifications.

"In addition to the samples submitted with the bid, other samples taken from and actually representative of the refined asphalt, petroleum flux, sand filler and binder stone to be used upon the street shall be submitted to the Engineer before the use of such materials in the work is permitted. Except at his option, no work on binder or surface shall be commenced within 3 weeks from the date when such samples were submitted and in no case shall they be used until they have been examined and approved by him. Whenever, during the course of the work, new deliveries of paving materials are received by the Contractor, samples of these shall at once be submitted to the Engineer and their use in the work will not be permitted until they have been examined and approved by him.

"**9. Asphalt Cement Preparation.** The asphalt cement shall be composed of refined asphalt, or asphalts and flux, where flux is required, of the character elsewhere herein specified and must be of a suitable degree of penetration.

"The proper proportions of the refined asphalt, or asphalts, and flux shall be melted together at a temperature between 135° and 204° C (275° and 400° F) and thoroly agitated by suitable appliances until they are completely blended into a homogeneous asphalt cement. Thereafter the asphalt cement must not be heated to a temperature exceeding 177° C (350° F). If the asphalt cement contains material that will separate by subsidence while it is in a molten condition, it must be thoroly agitated before drawing from storage and while in use in the supply kettles. Excessive agitation with steam or air which will injure the cement must not be used.

"The refined asphalt or asphalts and flux comprising the asphalt cement shall, when required, be weighed separately in the presence of the authorized inspectors or agents of the Engineer.

"**10. Asphalt Cement Requirements.** The asphalt cement shall comply with the following requirements:

a. It shall be thoroly homogeneous.

b. It shall have a penetration at 25° C (77° F) of from 30 to 55 for heavy traffic streets and 55 to 85 for light traffic streets depending upon the sand and asphalt used and the local climatic conditions.

c. It shall not flash below 177° C (350° F) when tested in a closed oil tester.

d. When 20 g of the asphalt is heated for 5 hr at 163° C (325° F) in a tin box, 2½ in in diameter and ¾ in deep, after the manner officially prescribed, the loss shall not exceed 5% by weight and the penetration at 25° C (77° F) of the residue left after such heating must not be less than one-half the penetration at 25° C (77° F) of the original sample before heating.

e. Either the asphalt cement or its pure bitumen when made into a briquette, Dow mold, shall, at 50 penetration, 25° C (77° F), have a ductility of not less than 30 cm at 25° C (77° F); the two ends of the briquette to be pulled apart at the uniform rate of 5 cm per min.

When the asphalt cement as used has a penetration other than 50 at 25° C (77° F) an increased ductility of 2 cm will be required for every 5 points in penetration above 50 penetration and a corresponding allowance will be made below 50 penetration."

Comments and Explanations of sections of the Am. Soc. Mun. Imp. 1916 specifications.

Sections 4 and 10. Under these specifications asphalt prepared by refining hard native bitumens, soft native bitumens and asphaltic petroleums or combinations thereof are admitted provided that the refining processes are carried on in such a way as not to injure the materials and provided that the finished product is or is capable of producing an asphalt cement possessing the essential qualities for paving work.

Section 4, Paragraph 2. Different asphalts possess different properties in varying degrees and it is the sum of these properties which determines their fitness for paving work. In establishing a minimum permissible standard for each essential quality it is obvious that any one asphalt will probably exceed this minimum in one or more instances. It is not intended to encourage the production of an asphalt which shall only just pass the minimum requirements in every respect. Hence the clause in the second paragraph of section 4 requiring that all asphalts "shall be equal in quality to the recognized standard for its particular kind or type of asphalt" and to insure this, provision is made for inspection at the refinery. Asphalts made from a certain crude might be so treated as to injure them materially and yet just bring them within the minimum requirements.

Section 4, Clause a. Comparative uniformity in consistency or penetration is very desirable as tending to produce uniformity in the asphalt cement prepared at the paving plant, as once the requisite amount of flux is determined, it will not have to be changed materially. Marking the barrels with batch numbers makes it possible to sample the contents of a car satisfactorily without opening an excessive number of barrels. Without this precaution, three or four samples taken from a car containing barrels from several batches might all come from the same batch.

Section 4, Paragraph 3 and Clause b. Overheating or too prolonged heating is herein guarded against.

Section 5. This provides generally for the use of a suitable flux and one which, regardless of its composition or characteristics, must combine with the refined asphalt used to produce an acceptable asphalt cement. Fluxes might pass all the tests prescribed and yet be unsuitable for use with a given asphalt even tho they were satisfactory with other asphalts.

Section 5, Clause a. This provides for a liquid flux because without this provision certain solid asphalts might be claimed to be fluxes and therefore exempted from the requirements governing solid asphalts.

Section 5, Clause b. This prevents the use of too light or too heavy a flux.

Section 5, Clause c. This limits the percentage of light oils and the hardening due to their evaporation. A flux which hardened unduly under heat would produce an asphalt cement which would harden rapidly in the kettles and in the pavement after it was laid.

Section 5, Clause d. This insures a flux which will not produce dangerous quantities of inflammable vapor when used in the plant.

Section 5, Clause e. To a certain extent this clause is intended to prevent overheating to such an extent as to decompose the flux or crack it to an undesirable degree.

Section 6. This specifies the kind and size of stone to be used for binder and would appear to call for no detailed comment other than that which already has been given under BINDER STONE.

Section 7. This describes the sand. The limits given are sufficiently wide to provide for both light and heavy traffic mixtures. These limits are of course wider than should be applied to any particular set of conditions. Under the provisions of this section the engineer may and should narrow the limits to suit the conditions prevailing upon the streets to be paved and the available local material. This is fully discussed under SAND.

Section 7, Paragraph 4. The provisions of this section are in accord with the principles discussed under FILLER.

Section 8. This is an important section, more especially where it relates to the samples to be taken from the materials which are actually to be used in the work and have been assembled for that purpose. Bidding samples are required of only the refined asphalt, flux and asphalt cement and these of course must comply with the requirements of the specifications in order to insure consideration of the bid. Bids

are frequently made a long time in advance of the work and it often happens that the materials supplied to the contractor are not exactly the same as his bidding samples. When the variation is slight, this is not an important matter, but he should not be permitted to change the character and kind of the materials without the knowledge and consent of the engineer. Samples of sand and stone, if obtained from dealers, frequently differ greatly from actual deliveries made by them. For this reason, samples should be taken from actual deliveries before too great an amount has accumulated at the plant. If the samples are unsatisfactory, rejection will then not work great hardship to the contractor. It is often difficult to obtain satisfactory sand and it may be necessary to prospect for and open new pits. This takes considerable time and unless the samples are secured sufficiently in advance, laying of the binder and surface may be delayed, which in many cases is very undesirable. Contractors are prone to delay the furnishing of working samples until the last moment, hence the provisions contained in this section as to the time for handing in these samples.

Section 9. This describes the preparation of the asphalt cement and involves principles previously discussed at length. The provision for a maximum temperature of 204° C (400° F) during fluxing is to provide for those asphalts which are difficultly soluble in the flux. Once the solution is complete, the maximum temperature is limited to 177° C (350° F).

Section 10, Clause a. This clause is intended to insure that the flux and refined asphalt are in complete solution and that any finely divided mineral matter which the asphalt cement may contain is evenly and uniformly distributed thruout its mass.

Section 10, Clause b. This provides that the asphalt cement shall be of a suitable consistency (penetration) for the use intended. The reasons for varying the penetration in accordance with the traffic are fully discussed under THEORY OF SHEET-ASPHALT PAVEMENTS.

Section 10, Clause c. This insures an asphalt cement which will not produce dangerous quantities of inflammable vapor when used in the plant and also limits the amount of light oils which it may contain.

Section 10, Clause d. This also limits the percentage of light oils which the asphalt cement may contain and prevents the use of an asphalt cement which would harden too rapidly in the kettles and in the pavement. The test described herein indicates the extent to which bitumens in the course of time lose their more volatile hydrocarbon constituents and the hardening resulting from volatilization and chemical change. It may be considered as an accelerated exposure test and the limits given have proven safe in actual practice.

Section 10, Clause e. The necessity for ducility has been fully discussed under ASPHALT CEMENT and THEORY. The test described herein measures approximately the cementing value of a bitumen but is not necessarily a measure of the relative cementing value of different bituminous materials, or the same bituminous material at different temperatures. With the same bitumen an increase in penetration (softening) results in an increased ductility provided a suitable softening agent is used. The introduction of mineral matter into a bitumen frequently reduces its ductility. For these reasons the minimum allowable ductility is stated at 50 penetration at a standard temperature 25° C (77° F), and if an impure asphalt cement, in the state in which it is used, falls below the standard of ductility, the pure bitumen which it contains must be extracted and tested before the material is condemned. If the pure bitumen meets the test the material is acceptable so far as this clause is concerned. Asphalt cements as used are frequently above or below 50 penetration. An approximate correction allowance is therefore established permitting the testing of such asphalt cements at the penetration at which they are to be used.

CONSTRUCTION

13. Plant and Tools

Operations. In the manufacture of bituminous pavements by the mixing method, three distinct operations are involved; viz,

1. Drying and heating of the mineral aggregate,
2. Preparation and heating of the asphalt cement or bituminous cementing materials,

3. Mixing the hot mineral aggregate with the hot asphalt cement.

In a properly designed plant, the machinery for carrying out each of these operations must be capable of handling sufficient material to insure the required output. Take, for instance, a sheet-asphalt plant having a capacity of 2000 sq yd of 2-in wearing surface per working day of 10 hr. A sq yd of surface mixture 2 in thick when compressed will average 200 lb in weight. The total weight of the output will therefore be 2000 × 200 or 400 000 lb. This mixture will consist approximately of: Sand, 79%; dust or filler, 10%; bitumen, 11%.

The different portions of the plant must, therefore, be capable of handling the following quantities of material:

Drier,	316 000 lb	= 126.4 cu yd sand,
Melting tanks,	44 000 lb	= 22 tons pure bitumen,
Mixer,	400 000 lb	= 200 tons surface mixture.

In order to more fully appreciate just what is required of an asphalt plant, it will be necessary to consider briefly the kind of raw materials used in it and the conditions under which they are handled.

Sand. Depending upon the temperature of the air, this requires to be heated to between 177° and 204° C (350° and 400° F). While actual paving work is not usually carried on in rainy weather it is nevertheless frequently necessary to run very wet sand or stone thru the drier owing to its having been exposed to the weather or because freshly dredged sand is being used. Unless ample drier capacity is provided, therefore, the output of the plant when using wet sand will be greatly reduced. Many pavements are laid late in the fall or in early winter and under these conditions much greater drier capacity will be required than in warm weather, if the maximum output of the plant is to be maintained.

Asphalt Cement. This is ordinarily made by mixing together the requisite proportions of refined asphalt and heavy fluxing oil, altho it is sometimes purchased of the proper consistency for use. The asphalt cements in common use contain from 60 to 100% of pure bitumen. In order to produce a pavement containing a fixed percentage of bitumen it is necessary to use much more of an impure asphalt cement than of a pure one. Plants designed for use with impure asphalt cements will therefore require much greater melting kettle capacity than if pure asphalt cements were to be employed. There are a number of plants upon the market which, while admirably designed for use with pure asphalts, have far too limited a melting tank capacity to permit of anything like their normal output being maintained if an impure asphalt is used in them.

Mixture. The capacity of the mixer in a plant of the size under discussion is usually rated at 9 cu ft. This means that the batch dumped into it contains 9 cu ft of sand plus the other ingredients. Dry hot sand will average about 95 lb per cu ft. In accordance with the formula previously given and assuming that a pure asphalt cement is being used, each batch would therefore consist of the following: Sand, 855 lb; filler, 108 lb; asphalt cement, 119 lb; total weight, 1082 lb. It will take 370 batches of this size to turn out the required amount of surface mixture. In a 10 hr working day this means 37 batches per hr or one batch every 1.62 min. Not less than one full minute with a mixer speed of 60 to 80 rev per min should be allowed for actually mixing each batch of surface mixture. This leaves a total of only 37 sec in which the mixer must be charged with the various ingredients and the finished mixture dumped into the wagons. With a well organized gang and a properly working plant, 20 sec is all that is neces-

sary, but it can readily be seen that this is one of the points where seconds count. The mixer capacity of a plant is usually figured very closely and this makes it more than ever necessary that the melting tank and drier capacity should be ample to furnish a continuous and uninterrupted supply of hot sand and asphalt cement, as it is almost impossible to make up for delays at the mixer. Increasing the size of the mixer would at first appear to be a very simple way of providing against mishaps and this is quite commonly done in stationary plants. Increasing the size of the batch, however, means increasing the size of the engine, and this, in turn, means increased boiler capacity, both of which are very serious considerations in a portable plant. For this reason the average size mixer on a portable plant does not exceed 9 cu ft. Many foremen when trying for a record run will reduce the time of mixing their batches, but this is a practice which should never be permitted, as an insufficiently mixed pavement can not be expected to last.

The question of maintaining a maximum output is more serious in a paving plant than in many other lines of manufacture. To a partial extent, the unit cost of a reduced output may be kept down by employing a suitable number of laborers at the plant. The street gang, however, must be maintained at full efficiency and as they are trained men, they are usually kept under full pay. A gang organized in the morning to take care of 2000 sq yd of pavement can not be reduced on short notice so that they can lay a total of only 1200 sq yd during the day at the same unit cost.

A consideration of just what is required of the various parts of a plant follows:

Drying and Heating Machinery. This may be subdivided into: Cold sand elevator and drier; hot sand elevator; hot sand storage bin and screen.

Drier and Cold Sand Elevator. In the ordinary revolving drum drier the drum shells are made of $\frac{7}{16}$-in steel plate with butt strapped joints and are carried at one end by a four-armed spider and at the other end by a head, both of cast iron. The bearing at the hot sand end takes the thrust, being grooved similar to a propeller-shaft bearing and the cap is cored to form a water jacket, by means of which the bearing box can be kept cool. Sheet-steel shelves are rivetted the entire length of the interior of the drum, which give additional heating surface and constantly stir the sand. The combustion gases pass along under the drum in thru the discharge opening, back thru the interior, coming in contact with the falling sand and finally pass out thru the cold sand chute to the fan. In a permanent setting the drums are supported on steel work which is independent of the brick side walls, hence the drums expand and contract without affecting the brick work, and the latter is not subjected to vibration. In a portable setting, the ends are the same as in the permanent setting. The sides are made of steel plate lined with fire brick. The roof consists of two steel plates, the inner and heavier one being grooved to conform to the arc of the drum, thus holding the heat against the drum. The outer plate is carried straight across to form a rain shed. The cold sand elevator, which serves to convey the cold sand from the ground or bin to the drier, is usually of the bucket elevator type. In another type of drum the products of combustion pass thru a central cylinder to which are rivetted sheet-steel shelves. They then run thru the drier between the outer and inner drums and finally pass thru the exhaust fan to the stack. The outer shell of the drum is also provided with sheet-steel shelves which are rivetted

to it. There are also direct heat rotary driers of the single shell type in which the hot furnace gases come in direct contact with the material to be dried. They are provided with elevating shelves arranged in substantially the same manner as those in the other two types of driers already described. In still another type of drier, three-quarters of the hot air and gases enter the cylinder by way of hooded inlet openings. The balance enters thru the rear end of the drum. By the admission of cold air thru the sliding doors in the drier setting, the temperature of the heated air and gases toward the rear end is regulated to suit the material as it becomes drier. The lowest temperatures and the least circulation are found at the rear end of the cylinder, where the material is most dry and dusty. All three types of driers or heating drums are continuously revolved and are lower at the discharge end than at the inlet end, thus insuring the gradual passage of the material to be heated from one end to the other. The essential principle involved in drying a sand is to bring the various particles in direct contact with a large volume of hot air which takes off and carries away the moisture. No matter how much heat is applied to the sand, it will not dry it unless ample means are provided for carrying off the moisture which it contains. For this reason, almost all the modern types of driers have induced draught. In the earlier types of drums where this principle was not fully recognized, it was no uncommon thing to have hot sand delivered at the discharge end of the drier in which the space between the grains were filled with steam and when this sand cooled down it was often found to be quite wet.

Hot Sand Elevator and Screen. This is usually of the bucket type and is ordinarily enclosed to prevent loss of heat. It takes the sand from the discharge end of the drier and delivers it thru a revolving screen, which rejects the coarse particles of gravel, etc, to the hot sand storage bin.

Hot Sand Storage Bin. This varies greatly in size and shape and is provided with an overhead revolving rotary screen. The capacity of these bins is ordinarily from 5 to 15 cu yd, and, within reason, the larger they are the better. When using a very wet or very cold sand that is difficult to dry and heat to the proper temperature, this bin is sometimes filled over night or before the rest of the plant is started in the morning, thus insuring sufficient sand to keep the mixer running at full capacity. Very frequently the temperature of the sand delivered by the drier varies considerably from time to time but this equalizes itself to some extent in a good sized storage bin. When the sand is taken directly from the drier, much of it will often have to be dumped and discarded as being entirely too hot or too cold. The importance of a storage bin of ample size can not be too strongly emphasized.

Melting Equipment. This includes: Asphalt elevator; flux tank; melting tanks; draw-off tanks.

Asphalt Elevator. This is employed to convey the refined asphalt, either in barrels or broken up, to the melting tanks.

Flux Tank. This holds a supply of the heavy oil or flux used to soften the refined asphalt to the proper consistency for use. It is usually provided with steam coils to keep the contents fluid and should be equipped with a measuring gauge so that the quantity drawn off from it may be accurately measured. The flux is usually pumped from it directly to the melting tank, altho it is sometimes pumped into a smaller tank set on a scale so that the amount used may be weighed or more accurately measured than is possible in a large tank.

Melting Tanks. These vary considerably in size but average about 10 tons capacity. They are heated either by direct fire or by steam coils, and, where impure asphalts are used, must be provided with suitable agitators to keep the mineral matter in suspension and prevent it from coking on the bottom of the tanks, and, also, where draw-off tanks are not used, to insure a supply of asphalt cement of uniform purity to the mixer. This is a matter of very great importance, as shown by the following: Assume that an asphalt cement is being used containing 70% of bitumen and 30% of finely divided mineral matter that will settle to the bottom unless constantly and thoroly agitated. If the agitation is insufficient the upper portion of the tank may easily contain an asphalt cement carrying 80% of bitumen while in the lower portion the bitumen contents may fall to 60% of bitumen or less. The formula for the mixture is set on the assumption that the asphalt cement contains 70% of bitumen and in the ordinary method of procedure these proportions would be adhered to thruout the day's run. Assuming that the formula used was: Sand, 800 lb; dust, 100 lb; asphalt cement, 150 lb; total weight, 1050 lb. An 80% asphalt cement would give a mixture containing 11.4% bitumen, a 70% asphalt cement, one containing 10.0%, and a 60% asphalt cement, one containing 8.6%, or a variation of 2.8% of bitumen in the composition of the mixture. Ordinarily a mixture which requires 10% of bitumen to make a good pavement would be dangerously low in bitumen if only 8.6% of bitumen were put into it. Occasionally a crude attempt is made to roughly provide for this by putting in 5 or 10 lb more asphalt cement when drawing from the bottom of the kettle, but this, besides being mere guess work, is totally insufficient, as in the case under consideration it would require 180 lb or 30 lb more of 60% asphalt cement to bring the bitumen contents of the mixture up to the desired 10%. When using hard asphalts of high melting point which can be broken up into small pieces, a melting tank provided with steam coils presents many advantages. The heat comes directly into contact with a larger number of pieces of asphalt and the contents of the tank are more quickly melted and with less danger of burning than when direct fire heating is employed. The pipes should be extra heavy and continuous; that is, without joints, to minimize the danger from leaks which would cause foaming and overflow of the asphalt cement. When softer and more readily melted asphalts are used that in hot weather are impossible to break up into small pieces, the advantages of steam melting are not so apparent. The large pieces of asphalt when carelessly dumped into the tank are liable to bend or break the coils, unless they are protected by a strong grid, and the melting is easily and quickly accomplished without danger of burning by direct heat. Where steam coils are used, larger boiler capacity must be provided and the best type of mechanical agitators can not be installed owing to the obstruction offered by the coils. Agitation by means of steam or air jets must be resorted to and these harden up the asphalt cement much more than the mechanical type of agitators. Mechanical agitators usually consist of paddles attached to a revolving horizontal shaft having a very small clearance between the paddles and the bottom and sides of the tank. Mechanical agitators, if placed in the melting tanks, are liable to be broken by careless charging of large lumps of asphalt and for this reason many plants are provided with a drawing off tank.

Drawing-Off Tanks are ordinarily of the same capacity as the melting tank. As soon as the charge in the melting tank is melted, it is trans-

ferred to the draw-off tank, which is provided with an agitator and means for heating it and its contents kept thoroly mixed. With most pure asphalts little or no mixing is required and the flux combines so readily with them that a small air jet or a slight agitation with a wooden paddle is all that is necessary. With such asphalts a few hours is sufficient to melt and thoroly incorporate the flux with them, whereas with others from 10 to 12 hr in the melting tanks is absolutely essential to insure proper and uniform results. Some draw-off tanks are provided with air-tight covers and the melted asphalt cement in them is blown over thru steam-jacketed pipes by air pressure directly to the mixer. In others a pneumatic lift is employed consisting of a small air-tight tank which is filled from time to time as necessary and from which the hot asphalt cement is delivered to the mixer by means of air pressure when desired. In some plants pneumatic asphalt lifts are used as a substitute for drawing-off tanks. These are provided with a tank of small capacity which is automatically filled from time to time from the melting tank. The asphalt cement flows by gravity into the lift. When the lift has been filled in this manner, the air cock is opened to pressure fróm the air tank; a check valve in the inlet pipe closes, preventing the cement from running back to the tank, and it is then forced up the vertical outlet pipe over to the asphalt cement bucket. All asphalt piping is steam jacketed.

Mixing Machinery. This may be subdivided into: Sand measuring box; dust measuring box, bin and elevator; asphalt cement bucket; mixer.

Sand Measuring Box. This is placed directly under the hot sand bin and in the older types of plants the sand was measured by volume. The box, which was open at the top and rectangular in shape, was hung on trunnions, which allowed its contents to be dumped into the mixer. It was filled a little more than full and struck off with a straight-edge, thus insuring the use of a fairly uniform quantity of sand. Other types are enclosed and fixed, and when full the sand spouts out of a small hole in the filling chute. The best type of box, however, is the open one provided with a beam scale and in which a definite number of pounds of sand is placed at each filling. In an open type box the temperature of the sand is readily tested as often as necessary and if hung on trunnions the sand when too hot or too cold may be dumped on the platform and does not have to be discharged into the mixer and then dumped, which latter proceeding usually necessitates pulling out the wagon which stands under the mixer ready to receive its contents of finished surface mixture. Changes in the mixture and the weight per cubic foot of different kinds of sands can also be much more readily made and determined than with the other types of boxes.

Dust Measuring Box, Bin and Elevator. A sufficient supply of dry dust must also be provided for at the mixer. Some plants have dust elevators and bins and measuring boxes designed on the same lines as the similar devices for handling sand. In others a bin is provided on the floor of the mixing platform and the dust is measured into pails whose capacity has been ascertained beforehand and then dumped by hand either into the sand box or the mixer. The dust is used cold and as only a small proportion of it enters into the composition of the pavement, the storage facilities are on a much smaller scale than those provided for sand. In some cases the dust is weighed directly into the sand measuring box which is provided with a double beam scale for this purpose.

Asphalt Cement Bucket. This should preferably be provided with a beam scale similar to the sand measuring box. A double beam with a

separate weight for the tare is to be recommended, as the accumulation of asphalt cement in the bucket changes the tare from time to time. Some plants still use a measuring gauge, but this is not nearly as accurate as a scale. This bucket is usually suspended on trunnions by means of which its contents are readily dumped into the mixer.

Mixer. This is a plain or steam jacketed iron box provided with two horizontal shafts to which blades are attached. These blades have a pitch resembling those on a propeller and when in motion throw the mixture from the sides and ends of the box toward the middle. They are usually run at from 60 to 80 rev per min. The blades are detachable so that worn ones may be readily replaced and the shafts should be arranged so that they may be easily removed from the box. This permits readily changing without undue delay to a new set of shafts in which the blades are not set so closely together. This is a necessary provision when running coarse stone or binder mixture alternately with surface mixture. The box of the mixer is provided with a dumping slide on the bottom by means of which its contents, after mixing, may be quickly discharged into a wagon waiting below.

Portable and Semi-Portable Plants. The necessity for building plants which were capable of a large daily output and which could at the same time be moved from place to place without undue expense led first to the development of the so-called semi-portable plant, and, secondly, to the development of the railway plant.

Road Plants and Road Machinery. In modern road building where bituminous roads are constructed by the mixing method, it has become necessary to evolve yet another type of plant which may be moved from place to place along country highways when railroad transportation is out of the question. In some of these plants all the machinery has been placed on one unit; in others, two have been employed, and in still others, the plant has been subdivided into three units. Any substantial departure from standard sheet-asphalt practice and design in them should however be viewed with suspicion, as, regardless of the plant, the principle involved in the manufacture of paving mixtures remains or should remain the same if successful pavements are to be laid and they must not be sacrificed for the sake of portability.

Tools. The special tools used in the asphalt industry are: Wagons, shovels, rakes, tampers, smoothers, sandals, asphalt cutters, fire wagons, surface heaters, and rollers.

Wagons. While ordinary dump carts or wagons are sometimes used, a special form of dumping wagon which is cut under so that it may be readily turned in a narrow street is desirable and is usually employed by all the large paving companies. They should preferably be lined with sheet iron to facilitate the removal of the mixture from them. A body constructed entirely of iron would be undesirable because during long hauls in cold weather the mixture would lose too much of its heat by radiation. Where circumstances will permit, motor trucks can be used to advantage, as work can be carried on at much greater distances from the mixing plant.

Shovels. These are of the ordinary short-handled, square-ended variety of contractor's shovels, but it is desirable to have the metal shank which takes the handle extend up some distance to prevent the burning of the wood when the shovel is heated in the fire. This heating is necessary in order to prevent the hot surface of binder mixture from adhering to them.

Rakes are extra strong and of a special pattern, having teeth about 3½ in in length and a long shank and metal socket to take the wooden handle and prevent it from being burned off when the rakes are heated.

Tampers are of cast iron with hollow iron handles and the tamping base is either square or rectangular in shape. The tamping face varies in size but is usually from 30 to 40 sq in in area. They are heated and used to compress the pavement around manholes, on joints, along street-car tracks and in gutters and generally in places where the roller can not reach.

Smoothers are of cast iron with hollow iron handles and have a rocker face so that they may be pulled back and forth over the pavement. They vary in dimensions and weight but usually have a face about 6 by 10 in. They are heated and used to smooth and heat joints and close up surfaces which do not close up properly under the roller, more especially in cold windy weather. Where the pavement is to be subjected to very wet conditions, they are sometimes used over the entire surface to bring the bitumen to the surface and close up the pores, thus preventing water from entering them. They should be used with extreme care and only be placed in the hands of highly skilled men, as there is great danger of burning the asphalt cement in the surface by the use of them.

Sandals are usually made of leather and are worn by the rakers and the men who have to walk on the newly laid surface, such as tampers, smoothers and cement sweepers. By their use sharply defined footprints in the hot pavement are avoided and they also serve as a protection to the men's feet and shoes.

Asphalt Cutters are used for cutting back the joints and cutting out portions of the pavement. They may be described as double-bladed axes of peculiar design having a blade shaped more like that of a mattock than an axe.

Fire Wagons are of iron with four wheels and of sufficient size to heat the shovels, rakes, tampers and smoothers used by the street gang. They are sometimes provided with racks from which to hang buckets of asphalt cement used to paint joints and around the edges of manholes, curbs, etc. Wood is preferred to coke or coal as a fuel in them, as the surface of tampers and smoothers are less liable to be pitted by it.

Surface Heaters are of various types and are used to dry foundations or soften old or defective pavements prior to repairing or resurfacing them. They are of three types; those using coke, gasolene or kerosene, and hot air and steam as softening agents. Coke heaters are usually iron fire baskets on four wheels of small diameter so that the bottom of the fire is only a few inches above the pavement. They vary in size, but 3 by 4 ft is about the average. Gasolene or kerosene heaters are of the Perkins or Wells type and have a reservoir containing the fuel. This is forced by air pressure to the burner which is protected by a metal shield which also serves to throw the heat and flame directly down upon the pavement. They are mounted on wheels. Hot air and steam heaters of the Lutz type are portable boilers provided with their own motive power. They force a blast of air and steam down on the pavement under a shield or hood which is 5 by 10 ft in size. They are very rapid in their softening action and are largely employed on resurfacing work. With a single one of these machines, from 500 to 1500 sq yd can be resurfaced in a day. In all three types of machines, heat is usually applied to the surface of the pavement until it has been softened to a depth of approximately 1 in. The softened surface

is then removed by means of rakes and shovels and while the bottom part of the old pavement is still warm new surface mixture is spread over it and rolled and finished in the usual way. In this way the upper portion of an old pavement may be quickly and cheaply removed and covered with an inch of new wearing surface at much less cost than would be involved in the complete renewal of the pavement.

Rollers. In some instances hand rollers are used to give an initial compression to mixtures which will not take a heavy roller while hot. This is sometimes desirable in cold windy weather with certain types of mixtures, to prevent the chilling of the surface and the consequent honeycombing of the pavement which would otherwise result if the heavy roller had to be kept off the surface mixture for a considerable length of time after it had been raked. In the early days of the industry hand rollers were always used to give the initial compression and they were sometimes heated by fire baskets suspended in them. Steam rollers are usually of the tandem type and vary in weight from 2½ to 13 tons, 8 tons being about the average. They should be balanced so that the weight on both sides is the same. Some of them are provided with power steering gear and others are steered by hand. In the very heavy types power steering gear is desirable. Gasolene rollers are undesirable, as they usually reverse with a jerk, which leaves a depression in the pavement which is very difficult to remove. A three-wheeled roller has also been used to a limited extent in England and on the Continent, the three rolls being of the same width and placed directly in line. It is claimed by the makers that with this type of roller there is less tendency to produce waviness in the finished pavement.

14. Methods of Manufacture

Asphalt Cement. Where it is necessary to flux a hard asphalt, care must be taken to see that the flux is free from water; otherwise the contents of the melting tank are liable to boil over and possibly take fire from the fires underneath. The flux as turned out by the manufacturer is usually free from water, but when purchased in large quantities is frequently shipped in tank cars provided with steam coils to facilitate pumping. Storage tanks are usually fitted with steam coils also. Where any leak occurs in these coils, water enters the flux and can only be removed by heating the flux above 100° C (212° F). During this process, copious foaming takes place and unless the tank has a large excess capacity it will foam over. If flux containing water is added to a tank already nearly full of hard asphalt, there will be insufficient room to take care of the foaming and the heat must necessarily be applied very gradually. Under these circumstances it sometimes requires 2 to 3 days to drive off the water and until it is driven off the asphalt cement can not be used. Either the flux should be freed from water in a separate tank or it should be put into the melting tank and the water driven off before any hard asphalt is added. In this way there will be sufficient excess space to accommodate the foam and the heating can proceed much more rapidly. Agitation, preferably with air, will materially assist in driving off the water and reduce the time necessary. The proportions of flux and hard asphalt to be used are usually determined by preliminary laboratory tests or drawn from previous experience with the same materials. Different deliveries of the same kinds of hard asphalt and flux often vary to a certain extent, which will render necessary a departure from the formula decided upon, but this can only be determined accurately by charging a kettle to its normal capacity and

testing the resulting asphalt cement. In laboratory tests on small samples, the conditions of heating and the relative amounts involved and the surface exposed to evaporation always differ from those found in practice. Careful record must always be kept of the weights of both hard asphalt and flux charged into the kettles. The flux is sometimes measured instead of being weighed and its weight calculated from its specific gravity. Assume that an asphalt cement of 55 penetration is desired and that the proportions required, as shown by tests or otherwise, are as follows: Hard asphalt, 100 lb; and flux, 10 lb; and that the charging record was hard asphalt, 20 000 lb, and flux, 2000 lb. Upon testing, the asphalt cement was found to have a penetration at 25° C (77° F) of 50 and the hard asphalt of 30. Evidently 10 lb of flux raised the penetration of 100 lb of hard asphalt 20 points (50 − 30). One pound of flux would therefore raise the penetration of 100 lb of asphalt 2 points (20 ÷ 10). The asphalt in question required to be raised 25 points (55 − 30) in penetration, which would require 12½ lb (25 ÷ 2) of flux per 100 of hard asphalt. The kettle contained 20 000 lb of hard asphalt and therefore should have had added to it 12½ times 20 000 divided by 100 or 2500 lb of flux. As only 2000 lb of flux were used, 500 lb (2500 − 2000) more must be added. Let it now be assumed that under the same conditions the asphalt cement was found to have a penetration of 60 and the hard asphalt of 30. Evidently 10 lb of flux raised the penetration of 100 lb of hard asphalt 30 points (60 − 30). One pound of flux, therefore, raised the penetration of 100 lb of asphalt 3 points (30 ÷ 10). The penetration desired for the asphalt cement was 55 and the penetration of the hard asphalt was 30, hence sufficient flux should have been used to raise the penetration of the hard asphalt 25 (55 − 30) points and this would require 8⅓ lb (25 ÷ 3) of flux for every 100 lb of asphalt. Stated in another way, the asphalt cement should contain 12 lb (100 ÷ 8⅓) of hard asphalt for every pound of flux. The charging record shows that 2000 lb of flux were used, hence 24 000 lb (2000 × 12) of hard asphalt should have been put in the kettle. As only 20 000 lb were put in, it will be necessary to add 4000 lb (24 000 − 20 000) more of hard asphalt. These calculations based on the softening power of the flux are sufficiently accurate for practical purposes but do not hold good over a very wide range. The softening power of 1 lb of flux added to a hard asphalt of 20 penetration will usually be less than the softening power of 1 lb of the same flux added to an asphalt cement of 50 penetration composed of the same asphalt and flux. After the kettle has been charged the heat should be gradually increased until the contents are completely liquefied, after which it should be thoroly agitated until the flux and asphalt are in complete solution. The time required for this depends upon the asphalt and flux used as some asphalts dissolve much more readily than others. The general practice is to charge the kettles at night and keep a slow fire under them, gradually bringing the temperature up to 149° C (300° F) by the morning. Very often the night watchman looks after the fires, or steam, if steam melting is used. Before starting work in the morning the contents of the kettle must be thoroly agitated. No asphalt cement should ever be drawn from a kettle until the contents are completely liquefied and thoroly agitated. If the asphalt used contains a considerable proportion of foreign matter which is liable to settle to the bottom of the kettles, agitation must be kept up while the asphalt cement is in use. Different forms of agitation are employed, mechanical agitation being the best for impure asphalts, such as Trinidad. With pure asphalts

requiring but little agitation, high pressure steam or air may be used, but both of these means of agitation tend to harden the asphalt cement and therefore should not be employed to excess. Steam is more liable to carry off light oils and air is liable to oxidize the asphalt and reduce its ductility. Care must be exercised in using steam agitation to see that no water enters with it into the asphalt cement as this will at once cause dangerous foaming. Some asphalts are more liable to injury from overheating than are others, and under ordinary circumstances it is best to set 149° C (300° F) as the maximum temperature to which the asphalt cement is to be heated. In certain cases, owing to low air temperature, very wet sand, long haul, or insufficient drier capacity, it may be necessary to increase this somewhat in order to turn out the mixture at a sufficiently high temperature to insure its being sufficiently hot when it reaches the work. Under these circumstances it may be permissible to heat the asphalt cement up to a maximum of 177° C (350° F), but this should never be exceeded. Grahamite and some varieties of Cuban asphalt which are very slow to dissolve in the flux may be heated for a short time up to 204° C (400° F) to facilitate solution, but once solution is complete the maximum temperatures previously stated should be adhered to. When work is stopped before the contents of a kettle are used up, the heat should be lowered or entirely withdrawn, depending on the duration of the stoppage. Every kettle of asphalt cement must be tested for penetration before it is put in use, and this also applies to asphalt cement left over from a previous day's run. Where it is suspected that the asphalt cement is hardening very rapidly in the kettles, additional penetration tests should be taken as it is being used up, and, if found necessary, more flux should be added to it from time to time. In such cases thoro agitation for ½ hr after the flux has been added will usually be all that is required to make the asphalt cement fit for use. Some few foremen can tell the penetration of an asphalt cement within three points by chewing it, but this should only be used as a guide and accurate penetration tests should always be taken. Flow tests have also been used to check the penetration of an asphalt cement, reference being had to a standard sample for comparison. Asphalt cements made from different asphalts and the same flux will have quite different flows, however, and this is true also of asphalt cements made from the same asphalt and different fluxes. For this reason the flow test is much less used at the present time than it was formerly, and in every instance requires that a check test be run on a standard sample made from exactly the same materials as the asphalt cement being tested. Wherever asphalt cement is pumped, the pipes and pump should be steam-jacketed and carefully drained when the plant is shut down, otherwise the asphalt cement will solidify in them.

Binder. As previously noted, this is composed of stone or stone and sand and asphalt cement. The preparation of the asphalt cement has already been described. When sand and stone are used, these should be kept in separate piles and should be mixed in the proper proportions in a small pile just in front of the cold sand elevator. In large plants provided with storage bins for raw materials the mixing is sometimes done automatically by means of feeding hoppers delivering on to a conveyor belt. Sufficient heat must be maintained under the drying drum to insure the delivery of the stone at the proper temperature to the stone bin. It is necessary to start the fires under the drier some time in advance of passing stone thru them in order that it shall work efficiently. The temperature

of the stone as it comes from the drier must be tested frequently. If it is too cold the rate of feed should be decreased and the fire increased and this should be reversed if the stone is too hot. By putting the drum fireman in charge of the feeding this can be regulated, but an experienced drum fireman must be employed if temperatures are to be kept uniform. Electrical pyrometers are frequently installed in the boot of the hot sand elevator and their recording dials placed where the drum fireman or feeders can readily see them. The pyrometer readings should be checked up from time to time with a thermometer as they are liable to derangement. The temperatures to which the sand and stone should be heated will vary, depending upon the air temperature, the length of haul, the proportion of sand used in the binder and the kind of asphalt cement employed. In cold weather with a long haul the binder mixture should leave the plant at a higher temperature than in warm weather with a short haul. A close binder, that is, one containing approximately 25% of sand, requires a higher working temperature than a binder composed entirely of comparatively coarse stone. Certain asphalt cements require higher working temperatures than others. The guiding principle should be to use temperatures which will not injure the materials and which will insure the delivery of the binder on the street at the most favorable temperature for laying and working it. Depending upon the different conditions stated, the temperature of the stone or stone and sand when it is put in the mixer should be between 107° C (225° F) and 177° C (350° F), but for any given set of conditions the limit of variation should not exceed 28° C (50° F). A certain drop in temperature always takes place between the boot of the hot sand elevators and the discharge of the storage bin, and this must be determined in each case and allowance made for it when establishing limits for temperatures taken at the boot of the hot sand elevator. Material which is too cold must be dumped and passed thru the heating drums again. Material which is only slightly overheated may be put in the mixer and allowed to cool off by agitation before the asphalt cement is added. When it has cooled down to the proper point the asphalt cement may then be added and the mixing continued in the ordinary way. If it is much too hot it should be dumped and allowed to become cool and again passed thru the drums. Segregation is liable to take place to a considerable extent in mixtures of stone and sand during their passage thru the heating drums and while in the storage bin. In many plants, therefore, the stone and sand after being heated are separated by revolving screens over the storage bins and are then recombined in definite proportions by weight before being put into the mixer. Some years ago the sand and stone entering into each batch were always measured by volume and this was also true of the asphalt cement. Modern practice is to weigh all the ingredients and this is much the better and more accurate way altho many of the older plants still use the volume method. After the various ingredients have been measured or weighed out, they are dumped into the mixer, where they should remain for from ½ to 1 min to insure thoro mixing. A close binder should be mixed for a longer time than is necessary for an open binder and the slower the speed at which the mixing shafts revolve the longer should the mixing period be. From the mixer the binder is discharged into wagons below. If the stone has been heated too hot the contents of the mixer will give off a peculiar blue smoke easily recognizable, and if the heating has been carried to a very high point, 204° to 260° C (400° to 500° F), the asphalt cement will probably take fire, in either case

the mixture should be dumped and discarded. In some cases old asphalt pavements are pulverized and used in place of sand. Where this is done the stone is heated separately and the requisite quantity of cold pulverized pavement is added to it just before it is placed in the mixer. This necessitates heating the stone to a higher temperature than would otherwise be necessary in order to offset the addition of this amount of cold material. The stone and old pavement should be mixed together for sufficient time to equalize their temperatures before adding the asphalt cement. Mixing should be continued until the bitumen is evenly disseminated thru the mass and each particle thoroly coated. Fat spots or accumulations of asphalt cement in the binder must be avoided as these will soften the pavement laid over them. As soon as the plant is shut down, mixer and asphalt cement bucket must be cleaned to prevent excessive accumulation of asphalt cement and binder mixture upon them.

Paint Coat. Where a cheaper form of construction is desired, a paint coat is sometimes substituted for the binder course. It is questionable, however, whether it is suitable for heavy traffic streets and in any case great care must be taken in its preparation and application in order to secure satisfactory results. It usually consists of asphalt or asphalt cement dissolved in gasolene or naphtha. In some cases gas engine distillate, heavy naphtha, or turpentine substitute is used instead of gasolene. Certain asphalts dissolve readily in naphtha and make a paint which will dry with a glossy surface. Other asphalts require the use of a heavier solvent as they are not sufficiently soluble in naphtha to make a glossy paint. Too heavy a solvent should be avoided, as paint made with it will not dry rapidly enough to permit the surface mixture to be laid on it shortly after the paint has been applied. As only comparatively small quantities of the paint are used, it is usually manufactured in a more or less crude way at the paving plants, either in small kettles or in barrels. If melting kettles are used the proper proportion, which varies with the asphalt and solvent used but generally averages about 5 lb of asphalt to 1 gal of naphtha, is melted in the kettle. The fire is then completely quenched and the naphtha is added in gradually increasing quantities, with constant stirring, until the asphalt is completely dissolved and the proper amount of naphtha has been added. If made in a barrel, the barrel is laid on its side and filled about one half its capacity with naphtha. Melted asphalt from a kettle is then poured in thru the bunghole in a fine stream and the mixture thoroly agitated from time to time by rocking the barrel. When the melted asphalt and gasolene first come into contact, the heat of the asphalt causes the gasolene to boil and inflammable vapors are given off which on a still day run along the surface of the ground for a considerable distance. For this reason the whole operation should be conducted not less than 100 ft away from any fire. The bung of the barrel should not be driven in until the solution is complete and has cooled off; otherwise the barrel may be burst by the pressure of the gasolene vapor. The paint when made should be tested before using it to see that it dries with a sufficiently thick glossy film to act as a cementing agent between the foundation and the wearing course. The paint coat when used is usually limited to concrete foundations, which should be quite smooth and have the mortar well flushed to the surface, or to old brick pavements which are being covered with an asphalt wearing surface.

Wearing Course. The first step in the manufacture of the surface mixture is the feeding of the cold sand to the drier. As previously noted

under SAND, it is almost always necessary to mix two or more sands together in order to get the proper grading. To insure a uniform mixture the proportions determined upon must not only be strictly adhered to but the different sands mixed must be reasonably uniform in quality. Deliveries, especially from small dealers who are not accustomed to the requirements of the asphalt business, often vary very greatly and for this reason must be carefully watched and tested. The different kinds of sand used must be kept in separate piles. If they become mixed it is almost impossible to turn out a uniform mixture. The various sands are usually wheeled to a pile just in front of the cold sand elevator and measured by wheelbarrow loads. A certain amount of preliminary mixing should be done by shovels before feeding them to the elevator. In some cases the sands are measured in a box or form as used in concrete. Where the main sand piles are close to the elevator, the sands are sometimes shovelled direct from the piles to the boot of the elevator, count being kept of the number of shovelfuls from each pile. If two sands are being mixed in the proportion of 2 : 1, two men would be placed at one pile and one man at the other pile and each man would be instructed to feed at approximately the same rate. Too much attention can not be paid to the mixing of the sand and frequent sieving tests should be made during the day to see that the desired result is obtained. Dry hot sand is very difficult to sample satisfactorily and for this reason it is preferable, wherever possible, to sample the wet sand being fed to the drums. Where the buckets of the cold sand elevator discharge into the feeding hopper of the drying drum some sand is usually thrown outside of the hopper and gradually accumulates in a small pile on some projecting beam or platform or the ground. By cleaning this away and sampling the accumulation during, say, 15 min, an excellent average of the sand fed thru the drum during that period is obtained. As this sand is usually damp, it can readily be sampled, after which it should be dried and sifted. A very great proportion of inferior pavements are directly traceable to lack of care in the selection and mixing of sands and failure to see that the sand deliveries were uniform and the piles kept separate. Where one of the sands is being used in small proportion, fairly thoro preliminary mixing before feeding to the elevator is essential. The regulation of the temperature of the heated sand is even more essential in a surface mixture than in a binder, as it is the wearing surface that is directly subject to the wear and tear of traffic and to climatic conditions. The temperature to which the sand should be heated is subject to the same considerations as those which govern the temperature of the binder aggregate; that is, as to denseness of mixture, weather conditions, length of haul and kind of asphalt used. Some mixtures rake very much stiffer than do others, due either to the kind of asphalt cement used, its penetration, the character and grading of the sand or the amount and kind of filler used in the mixture. Generally speaking, stiff raking mixtures require to be sent out at a higher temperature than do easy raking ones and the first load sent out in the morning and after the noon shut-down should be as hot as consistent with safety to insure a good joint with the cold material previously laid. Depending upon the above conditions, the permissible temperature limits for the sand as it is delivered to the mixer varies from 121° to 177° C (250° to 350° F), but for any one set of conditions the variation should not exceed 28° C (50° F), and the lower limits would only apply to easy raking and not very dense light traffic mixtures laid in the very hottest summer weather. Sand which is too hot or too

cold should be dumped and fed thru the drums a second time. Where the sand is very wet, mixing it with a certain proportion of dry sand or sand which is still hot will increase the output of the drier. Where the drier capacity is limited and the sand full of moisture it is sometimes necessary to run a considerable proportion of the sand thru the drier twice. The sand and dust for each batch should preferably be weighed out and a weighed amount of asphalt cement added to it in the mixer, altho some plants still adhere to the old method of measuring the various constituents. Once the formula for the mixture has been decided upon, it should be strictly adhered to and careless methods upon the mixing platform should not be tolerated. Each batch should be given a full minute's mixing after all the ingredients have been brought together and a less time for mixing should not be allowed. This is based upon the assumption that the blades of the mixer are in good condition and have a speed of from 65 to 80 rev per min. If the mixer speed is slower than this, the time should be correspondingly increased. In any event the mixing must be continued until all the grains are thoroly and evenly coated with asphalt cement. This is especially important where climatic conditions are severe, more particularly as regards rainfall. The more thoro the coating of each grain with asphalt cement the better will the pavement resist disintegrating influences. Every experienced painter knows the value of thoro rubbing in with a brush if he expects his painted surface to stand exposure. With a trained gang and a well equipped and designed plant, a batch can be turned out in 1½ min and still allow a full minute's mixing. Barring breakdowns or unforeseen delays, a plant should average in a day's run 1 batch every 2 min, but this means that the plant must be in good mechanical condition, the gang well broken in and no delays must occur in loading the wagon, and the temperature of the sand must be kept constantly within the proper limits. It is probably not too much to say that most of the failures in sheet-asphalt pavements have been due to improper sand and methods of manufacture and laying rather than to inferior asphalt. The character of the surface mixture being turned out should be carefully watched and the temperature of each load taken and recorded. In the hands of a trained man the mixture may be very closely regulated by the pat test, which is fully described under the head of inspecting and sampling methods. At a given temperature very small variations of bitumen in the mixture can readily be detected and any considerable variation in the mesh composition is plainly apparent on a careful examination of the smooth surface of the pat. After the mixing is completed the mixture is dumped into carts. In some plants, in order to reduce the time required for loading and overcome slight delays in the arrival of wagons from the street, a hopper similar to the box of the dumping wagon and of sufficient size to accommodate a full wagon load of mixture is placed directly under the mixer. This can be filled while waiting for the arrival of a wagon and its entire contents can be dumped as quickly as a single batch, thus permitting the work of the mixer to proceed uninterruptedly except in the case of serious delays to the wagon service. At the close of work the mixer and asphalt cement bucket should be thoroly cleaned as noted under BINDER.

15. Methods of Laying

Transportation. The hot material is brought to the street in carts, wagons or motor trucks and should be protected from the air while in

transit by canvas covers. With proper protection and suitable wagons, the loss in temperature of a load of hot binder or surface mixture should not exceed 5.6° C (10° F) in 2 hr when the air temperature is above 4° C (40° F). In extremely cold weather the loss will of course be somewhat greater. Besides being uneconomical very small loads are undesirable as they increase the number of joints in the pavement, more especially if they do not arrive on the street at regular intervals. Drivers during a long haul are very apt to wait for each other, which results in several loads reaching the street at about the same time. This, of course, causes a gap between subsequent deliveries. Loads of too large a size are objectionable, especially for surface mixture, as a large mass of material is liable to become so consolidated by the jarring incident to a long haul that it can only be removed from the wagons with great difficulty. In cities having large permanent plants the tendency is to run to maximum sized loads. In smaller towns and where the route of haul is hilly, the smaller sized loads prevail. The average load used thruout the country varies from 2 to 4 tons. The carts should be kept clean and if not provided with iron linings are usually whitewashed or oiled in the inside every day to facilitate the removal of the mixture from them. Two-wheeled carts are usually too small to give satisfac ory service for the reasons previously mentioned. Dumping wagons with a small turning radius are preferable, as they can deliver their loads and get away with little loss of time. The ordinary type of dirt wagon with removable bottom slats for dumping should be avoided, as the mixture cools off rapidly in them during transit and while being dumped and much of it is lost in the dumping process. Many contractors carry their own wagons or wagon bodies with them and hire local teams and running gear. In certain special cases, large quantities of hot mixture have been sent by rail or water for considerable distances. In such cases the mixture on the outside of the load will probably chill to such an extent that it should be discarded. Reheating the partially chilled material from the outside has been resorted to in such cases, but it is very liable to injure the mixture and should not be considered as standard or good practice.

Binder. The surface of the concrete should be dry and swept clean before laying binder upon it. A slight amount of dampness is not objectionable but the surface must be free from pools of water. Upon arrival at the street the load of binder mixture should be dumped on a spot near but outside of that on which it is to be spread. It is then roughly distributed by means of hot shovels over the area to be covered and final distribution is effected by hot rakes, after which it should be rolled with a steam roller of from 5 to 7 tons weight. Those portions of the surface which are not accessible to the roller should be tamped with hot tampers. An open binder of good quality should appear bright and glossy when it reaches the street and each particle of stone should be thoroly and uniformly coated with asphalt cement. If an insufficient amount of asphalt cement has been used, the stone will have a dull appearance, and this will also be the case if the stone has been heated too hot, in which event much of the asphalt cement will run off during transit to the street and may be found in pools in the bottom of the wagon. In either case the binder mixture will be lacking in bond and will probably break up under the roller or by the subsequent passage of wagons over it during the delivery of surface mixture on the work. Close binder containing a considerable proportion of fine material will not have this glossy appearance. When

fat spots showing an excess of asphalt cement are apparent, these must be cut out and replaced with other material. The practice of drying them with limestone dust and hot smoothers is not to be recommended. The mixture should reach the street at a temperature between 93° and 163° C (200° and 325° F), depending upon the composition of the binder and the air temperature. If too cold, it can not be raked and spread evenly or properly compressed under the roller. If too hot, it will be burnt or lacking in bitumen and will not bond together when rolled. Close binder should reach the street at a higher temperature than is advisable or necessary for open binder, as the latter variety is much more prone to lose part of its asphalt cement by draining during transit if the stone is too hot. If the binder is dumped on the spot on which it is to be spread, the bottom of the load will remain where it was dumped and will have been compressed to a certain extent by the weight of the material on top of it. The balance of the load will have been thoroly loosened up by shovelling and raking, whereas that which remains in the place where it was first dumped will only be loosened to a small extent by the rakes. When the entire load has been spread so as to present an even upper surface, that portion on which the load was dumped will be covered with a greater weight of binder mixture, owing to its increased density, than the other portion. When it has all been reduced to a uniform density by rolling, this will result in an uneven surface. This consideration, while important in the case of binder, is much more so when surface mixture is being laid. Concrete is rarely in this country laid to an absolutely true grade. One of the functions of the binder course is to fill in the depressions in the concrete and bring it up to an even surface parallel to the surface for the finished street. Binder is much cheaper than surface mixture and it is therefore to the interest of the contractor to see that all depressions are filled with binder and that the binder course, after rolling, is true to grade. This is desirable from another standpoint as well, for a wearing course which is of uniform thickness will wear more evenly and be less subject to displacement than one which varies greatly in thickness. While it is one of the functions of the binder course to fill up minor depressions, this should not be carried too far. Mistakes in grade in laying the concrete which result in depressions several inches in depth over considerable areas should not be filled in with binder, as it will be liable to displacement under traffic. Maximum compression is not as necessary with binder as with surface mixture and the rolling may therefore be delayed for some time after it has been spread, more especially if it is tender or has reached the street at or near the maximum allowable temperature. A good binder mixture properly compressed should not be damaged by hauling sufficient surface mixture over it to cover it. If it breaks up under these conditions it is evidence that it is of poor quality. An open binder in very cold weather is much more liable to be broken up in this way than a close binder and if found necessary, should be protected by planks. Generally speaking, as little hauling as possible should be done over the binder. The surface of the finished binder should be kept clean until it is covered with the wearing course, which should be put down as soon as possible.

Wearing Course. Before the mixture is spread, all dirt must be removed from the surface of the binder course and it is customary to paint the edges of manholes and gutters with a thin coating of asphalt cement to insure adhesion and prevent the water from finding an entrance at these points. This should be done with care, as too much asphalt cement

at any one point will enrich the adjacent surface mixture to an undesirable extent and may make it soft enough to cause shoving. The dumping and spreading of the surface mixture is carried on in the same way as with binder mixture except that more care must be exercised, as this material, when spread and rolled, will form the finished surface of the roadway. Great care must be exercised to thoroly fluff up or loosen the hot material to the same extent thruout and the precaution regarding dumping outside of the spot on which it is to be laid should be strictly observed. The rakers should not be permitted to stand in the hot material while raking it and for this reason no more should be deposited in place by the shovellers at any one time than can be handled by the rakers. They should work it up thoroly with their rakes and with a stiff dense mixture this is often hard labor. The temperature at which the mixture should reach the street depends upon its composition, the air temperature, and the physical characteristics of the materials used. The usual limits are from 110° to 177° C (230° to 350° F), but the lower limit only applies to the less dense light traffic mixtures made with asphalts which become extremely liquid at comparatively low temperatures and which are being laid in the hottest summer weather. Generally speaking, the temperature should be such that the mixture can be raked without too great difficulty, but very dense mixtures are always more or less stiff to rake and different sands, fillers, and asphalts affect this quality to a marked extent. Rounded sands tend to make easy raking mixtures and those containing limestone dust as a filler rake easier than those in which a Portland cement filler is used. Asphalts which do not liquefy readily under heat tend to make stiff raking mixtures. Much can be told concerning a mixture by observing how it acts when dumped from the wagon. Dense, heavy traffic mixtures stand up and the pile partly retains the shape of the wagon. This is true of the best type of heavy traffic mixtures regardless of what asphalt they are made with. Very rich mixtures will always be more or less sloppy and those made with hard asphalt cements will be stiffer than those made with soft asphalt cements. A mixture which appears dry and crumbly under the rake is usually deficient in bitumen and mixtures with normal sand grading and bitumen contents which lack cohesion are usually deficient in filler. Different asphalts have their own peculiar odor, and mixtures made with them frequently exhibit certain peculiarities by which they may be recognised by the trained eye. After the mixture has been spread and raked, it is tamped along gutters and railroad tracks and around manholes and is then rolled with a 5 to 10-ton roller. Some mixtures are quite tender when hot and will not stand a heavy roller without undue displacement which will result in a wavy pavement. In such cases it is sometimes advisable to run the lighter end of the roller over the surface first. When the weather is warm, rolling may be delayed until the mixture has cooled to a sufficient extent to stand the weight of the roller. Where it is cold and windy it is advisable to use a light steam or hand roller to close up the surface and prevent it from chilling on the top to such an extent that the pavement will appear honeycombed. Very hot mixtures will pick up by adhering to the roller, more especially if it is rough from being used on rolling grade. This may be remedied by keeping the rolls wetted with a mixture of kerosene and water. Steam may also be used to wet the rolls but flooding them with fine streams of water which run down on the surface of the hot mixture is not good practice. Kerosene and water is the best and it materially helps to close up the surface of the pavement

under unfavorable conditions. After the preliminary rolling, it is customary to sweep cement or limestone dust over the surface and then complete the rolling. This is often done too close to the freshly raked mixture and the dust is carried on to it by the wind, making it difficult to close it up properly. The dust should be kept off until the rolling is practically finished, as in this way defects in the surface are more easily detected and honeycombed spots may be readily closed up with a smoother. Once the dust has been swept on, it is difficult to detect minor surface imperfections and much more difficult to remedy them with smoothers. Generally speaking, maximum compression should be given to the pavement and this can only be secured by rolling while it is hot. The roller should therefore be run over the mixture just as soon after it is raked as the physical peculiarities of the mixture will allow and the rolling should be kept up as continuously thereafter as possible until maximum compression has been effected and the surface is smooth and true to grade. The more unfavorable the weather conditions, the more important it is that the roller should keep close up to the rakers. Rolling a cold mixture has little or no effect upon it. Rolling should at first be conducted parallel to the curb and each rolling should partially overlap the preceding one. When rolling straight work the point at which the roller stops on the first roll should be 2 or 3 ft distant from the point at which it stops on the second roll. The stopping point on the third roll may coincide with that on the first, and so on. In looking across the rolled work the points of stoppage of the roller will then form a staggered line across the street. A certain amount of mixture rolls up in a wave ahead of the roller and the method of rolling just described prevents the formation of a continuous wave across the street and makes it easier to finish the surface true to grade. Where the width of the street permits, it is customary to roll diagonally the second time and to finish by straight rolling parallel to the curb. Cross rolling is also sometimes used on wide streets and a skilled rollerman will vary his methods in accordance with circumstances and the peculiarities of the mixture. Quick rolling is not desirable, as it does not give the slow kneading action which is essential to thoro compression. Two hundred square yards per hour is about the maximum area of pavement that can be properly rolled by one roller and to do this satisfactorily the roller must be kept in continuous operation. Tampers and smoothers must be used with great care, especially the latter, to avoid burning the mixture, which will cause it to scale or grind out. Under favorable conditions with a suitable mixture the pavement should close up properly under the roller and the smoother only be required on the joints. Under unfavorable conditions it may be necessary to employ smoothers more extensively, but they should not be heated too hot and should be placed in the hands of skilled men. Any defects of surface, such as honeycombing, which requires their use should be given attention immediately after the pavement has received its first rolling, as it is then hot and a very short application of the smoother will suffice to close it up. After it is cold, there is much more danger of burning it, as the heat must be applied for a longer time. When fresh material is laid up against a cold joint it is always advisable to iron it so as to heat the cold pavement sufficiently to insure a perfect bond. In finishing a day's work provision must be made for joining new material to the pavement previously laid. One method is to roll the finished pavement to a feather edge and cut it back so as to expose a fresh surface of the full thickness just before commencing the next day's work. This cut should be bevelled and not ver-

tical. The exposed surface is sometimes lightly painted with asphalt cement but except in very cold weather this is not to be recommended owing to the liability of getting too much asphalt cement at certain points and thus softening the pavement in spots. The more modern and better method of making a joint is to attach a canvas flap to a ¾-in rope and lay this on top of the edge of the wearing course while it is being rolled and roll the pavement under it to its final compression. The rope is allowed to remain in place until just before work starts the next day, when it is removed and the new surface mixture raked upon the fresh surface thus exposed.

16. Inspection of Manufacture and Laying

Inspection of materials and processes during construction work may be subdivided into plant and street inspection.

Plant Inspection. During the progress of the work additional quantities of raw materials will from time to time be delivered to the contractor's plant. These should be sampled and examined in the manner previously described for the preliminary inspection of raw materials and no deliveries should be used in construction work until after they have been examined and tested and found to be in accordance with the requirements of the specifications. Owing to delays in the arrival of shipments this may at times be difficult, if not impossible, but in such cases, if it is inadvisable to shut down the work temporarily, the inspector should make all the tests possible at the plant in order to convince himself that the materials are suitable for the work. If he is able to determine definitely that they are unsuitable, they should, of course, be rejected and work shut down until other suitable material is available. At times it may be necessary for him to assume the responsibility of passing the materials and permitting their use pending an authoritative report from the central testing laboratory. Sometimes there will be but little risk in doing this; under other circumstances it may be advisable to permit the contractor to proceed with his work with the distinct understanding that if the materials are found not to comply with the requirements of the specifications he will take it up. Such an arrangement should only be made in writing and with the consent of the resident or supervising engineer. Where sand is delivered by wagon-load, it will usually be sufficient to take an average sample of the day's deliveries and test it. Where the sand is delivered by rail or barge, the contents of each car or barge should be tested, if possible before unloading it. These instructions apply also to stone and gravel. It is extremely important that deliveries of various grades of stone, sand and gravel should be kept separate.

Generally speaking, the processes involved in the manufacture at the plant of bituminous paving material are: Preliminary mixing and heating of the mineral aggregate; preparation and heating of the asphalt cement or bituminous binder; mixing of the heated mineral aggregate with the hot asphalt cement or bituminous binder.

Preliminary Mixing and Heating of the Mineral Aggregate. The proportions in which the various constituents of the mineral aggregate are to be mixed will, of course, depend upon their character and the specifications under which the work is being carried on. The method of mixing the different ingredients depends somewhat upon the feeding arrangements at the plant and the disposition of the raw materials. In certain large plants the raw materials are stored in bins. In some instances these bins

have automatic feeding devices which deliver the contents of the bins upon a conveyor belt. In such cases the automatic delivery devices should be set at the proper points and during their operation should be watched from time to time in order to see that they are delivering the desired quantity of material. With certain mixtures a mere inspection of the mixed aggregate as it is being fed to the heating drums will enable the inspector to roughly determine whether or not the proportions are being adhered to. With other types of mixtures this is very difficult to regulate by observation at this point. In the majority of instances, plants are not provided with storage bins of the type previously described and the materials are dumped in piles on the ground. These piles are usually arranged so that the material from them can be easily conveyed to the feeding device for the heating drums by means of wheelbarrows or horse slips. Where the mixture consists of sand and stone of various sizes, with a considerable proportion of stone, it is advisable to have the mixture made in a pile adjacent to the feeding device. This can frequently be done satisfactorily by having the requisite number of wheelbarrowfuls of the various ingredients dumped on a certain spot, this pile to be roughly mixed by shovels and then shovelled over into the feeding device. Where a simple mixing of two grades of sand is required, this can frequently be done satisfactorily by building a small box or boot around the bottom of the cold sand elevator and having the fine sand placed on one side and the coarse sand on the other side. One man on each of the two sand piles can then shovel the material into the box above mentioned in accordance with the mixing formula determined upon. Assuming that two parts of coarse sand were required to one part of fine sand, the man on the coarse sand pile would have to throw two shovelfuls of sand into the box to every one shovelful thrown by the man on the fine sand pile. The feeding of the sand thus thrown into the box would be attended to by a third man, who would feed it to the buckets of the elevator by means of a hoe or shovel. Usually the fireman who is in charge of the firing of the heating drums is able to supervise the operation of the feeding gang and see that they feed a properly proportioned mineral aggregate. In mixtures of sand and large sized stone there is liable to be a certain amount of segregation of the material in its passage thru the heating drums. Certain plants are provided with an overhead screen to separate the heated material after it comes from the drums into the various sizes and distribute them into different bins. The material contained in these bins is then drawn out into the measuring box in definite proportions according to weight. This, of course, is the most accurate method of making mixtures involving the use of a large proportion of relatively coarse stone.

The function of the heating drums is to dry and heat the mineral aggregate. Unless ample air circulation is provided for to carry off the moisture in the shape of steam, the drying will not be effectively conducted. It is essential to regulate the rate of feed and the temperature of the heating drums so that the mineral aggregate delivered from them will be dry and at the proper temperature. This operation is usually in charge of the fireman for the heating drums. The most modern plants are provided with a pyrometer inserted in the delivery chute from the heating drums. This pyrometer has a plain or recording dial which is placed at the feeding end of the drums, where it is under the observation of the drum fireman. This makes it easy for him to regulate his fires and the rate of feeding necessary to secure the desired results. Where no pyrometer is inserted, it is neces-

sary for him to test the temperature of the material issuing from the delivery end of the hot sand drums, from time to time, as often as may be required in order to produce satisfactory results. It is a comparatively simple matter to take the temperature of heated sand, but where the mineral aggregate consists of large stone particles, it is a much more difficult and unsatisfactory operation. Certain types of mixing plants are so constructed that it is very difficult to obtain samples of the hot mineral aggregate before it is mixed with the asphalt cement or bituminous binder. Regardless of the difficulty involved, it is good practice to test the temperature of every batch of mineral aggregate in plants of this type before it is mixed with the asphalt cement; otherwise uniform mixtures cannot be expected. Even when the greatest care possible is exercised, there will be considerable variation in the mesh composition and temperature of the mineral aggregate as delivered to the mixer. The permissible variations are usually set forth in the specifications and should be closely observed. Mixtures which vary very greatly in mesh composition will require different amounts of bitumen in order to make the best possible type of mixture. Within ordinary limits, no correction will have to be made for this, but, generally speaking, a mixture containing a large proportion of fine particles will require more bitumen to cover these particles than a mixture containing a smaller proportion of them. This is due to the fact that the finer the mixture the greater the surface area to be covered with bitumen. In order to secure a satisfactory output from the plant, it is absolutely essential that the greatest possible care should be taken in the mixing and heating of the mineral aggregate. In order to insure the proper mixing of the mineral aggregate, it will be necessary from time to time to take samples of the mixed aggregate and sift them for mesh composition. Owing to the extreme difficulty of securing an average sample of hot, dry mineral aggregate, great care must be exercised in selecting the samples. The arrangement of the plant and the kind of mineral aggregate used will determine where and how often these samples should be tested. Samples for test should be obtained from the overflow of the feeding device used in conveying the cold mineral aggregate to the heating drums. This is usually done by a chain and bucket elevator. Where these buckets dump into the chute at the entrance of the drying drums, there is almost always a small overflow which gradually piles up underneath this chute. Assuming this to be the case, the pile can be cleaned off at a given time and the material which accumulates during, say, a ½ hr run can then be sampled, dried and sifted. It is much easier to sample the damp material than it is the dry, and this not only obviates some of the difficulties attendant upon sampling dry material but gives the inspector an average of the material fed into the drums during the ½ hr while the pile was accumulating. In this way much better average results are obtained and the inspector is not liable to be misled by temporary and unimportant lapses in the feeding of the material. In other cases, samples of the hot material are obtained from the delivery end of the drying drums. In such cases a number of samples should be collected and mixed together and the resultant mixture sifted.

Preparation and Heating of the Asphalt Cement or Bituminous Binder. For the preparation of the asphalt cement or bituminous binder, the contractor may purchase a hard bituminous material and add sufficient flux to it to bring it to the proper consistency, or he may purchase an asphalt cement of the proper consistency for use without the addition of any flux.

In the first instance the melting kettles will have to be charged with the proper proportions of flux and hard asphalt to produce the desired asphalt cement. In large plants this is generally done at the close of the day's run. The materials are then kept under a gentle heat during the night and brought up to the desired temperature in the morning. The contents of the kettles are then thoroly agitated in order to insure complete mixing of the different ingredients and a sample from them is taken and tested for penetration before the contents of this kettle are permitted to be used. If it is too hard, more flux will have to be added to it. If it is too soft, more hard asphalt will have to be added to it. After the additions are thoroly melted, the contents of the kettle must be again agitated and tested before using.

In sampling the asphalt cement care must be taken to see that the sample taken really represents the contents of the kettles. Dippers in use in the kettles usually accumulate a considerable amount of dirt and hardened asphalt cement on them. The dipper should be immersed in the melted material for a sufficient length of time to thoroly soften all material adhering to it. It should then be used to stir up the contents of the kettle, which will further assist in cleaning the dipper. If the asphalt cement contains a considerable proportion of mineral matter and there is doubt as to the completeness of the agitation, the dipper should be immersed, bottom upwards, and held in that position until it reaches approximately the center of the kettle. It should then be turned right side up, thus filling it with material obtained approximately from the center of the tank. The sample when obtained should be protected from dust while cooling. Where the asphalt cement is piped to the measuring bucket, samples should only be taken from the delivery spout after sufficient material has passed thru it to insure getting a representative sample. Unless a circulation system is maintained by means of a pump, samples for determining the consistency of the asphalt cement before use should not be drawn from the piping system as it will contain too large a proportion of asphalt cement previously used. Certain asphalts are more difficult to flux than are others and require a longer period of heating. Overheating of the kettles will result in undue hardening of the asphalt cement. If the flux or hard asphalt contains any considerable proportion of water, this will foam very badly in the kettles and frequently cause them to run over. No asphalt cement or bituminous binder should be used until the water has been thoroly removed from it. Where the asphalt cement or bituminous binder contains a considerable proportion of mineral matter or impurities, the contents of the melting kettles must be kept thoroly agitated during the time that they are being drawn upon for use. Suitable mechanical agitation is, perhaps, the most advisable, as in this way the bituminous material is hardened less than if a steam or air blast is used.

Violent agitation with steam or air will very rapidly lower the penetration of the contents of the kettles. In the case of asphalt cements containing a considerable proportion of mineral matter, unless the contents of the kettles are thoroly agitated, the material drawn from them will vary in purity or bitumen content with the result that the portion first taken from the kettle will usually run much higher in bitumen than the portions last taken from it. Assuming that the proportions of the mixture have been set to give the desired quantity of bitumen, based on the average bitumen content of a thoroly mixed kettle, the mixture turned out with the asphalt cement first drawn from the melting kettle will be too rich in bitu-

men and that turned out with the asphalt cement last drawn from the kettle will be too low in bitumen. It is impossible to estimate by observation the changes in weights of asphalt cements necessary to overcome this and the only proper way, therefore, is to so agitate the contents of the melting kettles that the supply of bituminous material drawn from them will be uniform in bitumen content. If for any reason the asphalt cement for a certain day's run is not entirely used up, it should always be tested for penetration before permitting its use on a subsequent day's run. There is, of course, no objection to filling up the balance of the kettle with new material and mixing it thoroly with the portion left from the previous day's run. It should then be considered as a new batch of asphalt cement and tested accordingly. Where hard asphalt and flux are to be melted together, the contractor should never be permitted to draw any material from the melting kettles until their contents have been completely melted and thoroly mixed. Even where the asphalt cement is purchased ready for use, it is not good practice to draw from a kettle containing lumps of unmelted bituminous material. Sufficient melting kettle capacity should be insisted upon to avoid the necessity of doing this. With the exception of the fluxing, the foregoing remarks apply equally to bituminous binders, purchased by the contractor, of the proper consistency for use.

Mixing of the Heated Mineral Aggregate with the Hot Asphalt Cement or Bituminous Binder. It is unquestionably the best practice to weigh out the various ingredients entering into the composition of the finished mixture. Where the different ingredients are measured by volume, much greater variations will occur than when they are measured by weight. If measured by volume, the contents of the various measuring devices must be carefully checked up before the commencement of the work and the gauges set at the proper point. It is advisable to check up the setting of these gauges from time to time to see that they have not been displaced, either intentionally or otherwise. In determining the volume occupied by the desired weights of the different ingredients, it is necessary to measure them at the temperatures and under the conditions used in actual work. In other words, heated dry sand or stone must be filled into the measuring box and the weight of the box when filled to the proper mark determined. This is also true of the bucket or measuring device used for asphalt cement or bituminous binder. If the asphalt cement should contain any water, this will produce foaming and it will be impossible to measure it accurately. If the foaming is at all excessive, it will be impossible to get the required amount of asphalt cement in the ordinary sized measuring bucket. This, by itself, constitutes a sufficient reason for not permitting the use of any asphalt cement which contains water. Where the materials are measured by weight, the tare of the empty measuring devices must be carefully obtained and this tare added to the weight of materials which it is desired to use. In determining the tare of the asphalt cement bucket, it must be borne in mind that after an hour's run there is a considerable accumulation, amounting to several pounds, of asphalt cement on this bucket which will increase its tare above that obtained by weighing the bucket in a perfectly clean state. After once determining the tares and setting the weights or gauges at the proper point, their position on the scale beams or elsewhere should be checked up from time to time to see that they have not been displaced. Occasionally the accumulation of surplus material on the scale platforms of the measuring device for the mineral aggregate will change the tare somewhat. Any such accumulation should be removed as

often as necessary. Unforeseen happenings will occasionally influence the tare of the measuring devices. It was found in one case that the mixture being turned out was entirely too sloppy, altho but a short time before the tare and gross weights of the various ingredients entering into it had been carefully checked up. Upon investigation, it was found that the spout carrying the materials from the hot sand bin had been shifted by the vibration of the machinery so that it rested part of its weight upon the sand box, thus increasing its tare by approximately 200 lb. Each batch of mixture turned out under these conditions, therefore, contained 200 lb too little mineral aggregate, which, of course, accounted for its sloppiness.

The method of mixing varies in different plants. In the larger sized paving plants almost invariably the pug mill mixer, which is recognised as the best type, is used. The blades in this mixer should be examined to see that they are properly set and not unduly worn, thus producing an imperfect mixture at the bottom and sides of the mixer. Ordinarily they should revolve at a speed of from 60 to 80 rev per min. In mixtures of the sheet-asphalt type, one full minute should be allowed for mixing each batch of material. Where the mixture is a comparatively open one consisting largely or entirely of stone, this mixing time may be reduced somewhat. Whatever the type of mixer employed, the proper time for obtaining a thoro mixture should be determined and rigidly adhered to. The temperature of the mineral aggregate delivered to the mixer should be tested as often as may be necessary. This, of course, will depend upon the type of plant used and is a check upon the drum fireman and the feeding operations of the mineral aggregate. The temperature of the asphalt cement in the melting kettles should also be tested as often as may be necessary in order to be certain that it is uniformly maintained at the proper point. Where the type of mixture permits it, frequent pat tests should be taken of the material delivered to the wagons. This test is made by placing a small quantity of the hot mixture upon a sheet of unglazed manila paper, folding over the paper and pressing down upon it with a wooden paddle. After it is thoroly compressed, the paper should be struck a sharp blow with the wooden paddle and then opened for observation. An examination of the surface of the compressed mixture will clearly show to the trained inspector any marked variations in the mesh composition of the mineral aggregate. The depth of stain upon the paper will measure the amount of bitumen which it contains. The richer the mixture in the bitumen the heavier will be the stain. This stain is also influenced by the temperature of the mixture when the pat test is taken. For this reason it is necessary in comparing pats to know exactly the temperature. In obtaining the mixture for the pat test from the wagon, an ordinary mason's trowel will be found convenient. No time should be lost after obtaining the sample in putting it upon the manila paper and making the test; otherwise it will drop very considerably in temperature. The temperature of the material tested can be conveniently determined by inserting a thermometer at the place where the sample was taken from. Convenient and suitable arrangements for making this test should be insisted upon at the plant. This is a most important and valuable guide in the hands of a competent inspector and great attention should be paid to it. In the hands of a trained man, a variation of 0.25% of bitumen can be detected by means of the pat test. This pat test is, of course, not applicable to mixtures consisting chiefly of large particles of stone. The inspector should make careful notes of the various conditions surrounding

the plant. He should take and record at least three times daily the temperatures of the asphalt cement and the mineral aggregate as delivered to the mixer. He should also record his siftings of the mineral aggregate together with the proportions used in making the mixture and of the asphalt cement.

All deliveries of material at the plant should also be noted and a record kept of any tests made on them. These records should be kept on properly designed forms and should state the name of the street on which the mixture is being laid, the kind of mixture and the kind and proportion of the various ingredients entering into it. He should also keep a record of the number of batches turned out from the plant, as this is a valuable aid in checking up the thickness of the pavement laid on the street. At the commencement of the day's run it is customary to send out mixture which is a little hotter than that sent out during the average operations of the plant. This is done in order to enable the workmen on the street to make a close and intimate joint with the pavement laid during the previous day's run. While safe temperature limits should not be exceeded at any time, the maximum limits should be approached in sending out the first few loads in the morning.

Street Inspection. Prior to the delivery of any bituminous materials upon the street, the foundation must be completed in accordance with the requirements of the specifications. The finished foundation must then be swept clean of all dirt, etc. Knowing the type of mixture to be laid and the number of pounds used in each batch and the number of batches per wagon-load, it is usually possible to determine in advance how many square yards should be covered by each wagon-load. The best street foremen, before laying any bituminous material, measure the width of the street and calculate the number of linear feet which should be covered or pulled by each load. A tape is then laid along the curb and a chalk mark made at the point where the raked material from each load should end. Where the foundation is reasonably smooth and in accordance with the contour of the finished pavement, this method is one of the best checks for determining the thickness of pavement laid. Ordinary sheet-asphalt pavement, 2 in thick, will weigh 200 lb per sq yd. Pavements containing a large proportion of good sized stone will vary somewhat from this weight, but the exact weight per square yard can easily be determined during the first day's run.

As soon as the material reaches the street, its temperature should be noted. The hot material should be dumped outside of the spot where it is to be laid in order that all of it will have to be conveyed to its final resting place by means of shovels. This results in a preliminary spreading of material of approximately the same density. Where the load is dumped on the spot on which it is to be spread it will inevitably be tramped upon and certain portions of the heated mixture will receive more compression than others, which will eventually result in an uneven surface to the finished pavement. In certain classes of bituminous mixtures, notably those containing large particles of stone, where the haul is long, the coarser particles may settle to the bottom of the load. If this takes place to any great extent, the load when dumped should be remixed by turning over with hot shovels. In shovelling the hot mixtures into place the shovellers should not dig into the top of the pile but should shovel from the bottom of it, cleaning up the loose material as they go. If this is not done, the lower layer of the pile, in cold weather, will have become chilled by its contact

with the cold foundation and it will be difficult to remove it completely and uneven distribution and compression will result. The mixture, after having been deposited roughly in place by means of shovels, is spread by means of hot rakes. During this operation the rakers should not stand in the hot mixture any more than is necessary. Care should be taken to maintain a uniform and even grade so that there will be no depressions in the finished pavement which will hold water. Some mixtures compress very much more than others, so that it is impossible to establish any definite rule for the depth to which the hot mixture shall be raked.

As soon as possible after raking, the mixture should be rolled. Some mixtures are more tender than others and must be allowed to cool off somewhat before putting the hot roller on them. The hotter the mixture, the greater will be the compression and it is, therefore, desirable to roll it as soon as possible. In very cold weather, especially when a strong wind is blowing, the surface of the mixture will chill quite rapidly. With a tender mixture it is often advisable to use a light hand roller over it as soon as it is raked in order to close up the surface and then follow this with a heavy steam roller as soon as the mixture will bear it. Undue delay in rolling the mixture will result in a more or less honeycombed surface. Depending upon the contour of the street and its width, the rolling should be first done parallel with the curb. This should be followed by diagonal or cross rolling and the final finish of the work by rolling parallel to the curb again. The exact method of handling the roller can usually be left in the hands of the roller engineer if he is an experienced man, as he should know how to smooth up the finish of the pavement better than will the average inspector. At the finish of the day's work it is necessary to leave the pavement in such condition that a proper joint may be made with it when the next day's operations are commenced. There are a number of methods of doing this. Perhaps the best is the rope joint in which a length of rope is laid across the extreme edge of the pavement and rolled into it while hot. When this is taken up very little cutting back will have to be done and the edge will be left in such shape that a satisfactory joint can be made. The practice of painting these joints with hot asphalt cement before laying fresh pavement adjacent to them is to be avoided whenever possible, as the tendency is to put too much asphalt cement on the joint. This asphalt cement is absorbed by the hot mixture and softens it at that point and traffic is liable to displace it. For the same reason the painting of edges of curbs, manholes, etc, should be done with extreme care. A very convenient instrument for determining the depth of the finished pavement is a putty knife with a blade 2 in wide which has been marked across the face of the blade at a point corresponding to the required depth of the pavement. This can easily be inserted in the warm mixture after it has been rolled and the broad point will bridge over any small depressions in the foundation and avoid the recording of a greater depth to the pavement than really exists.

The use of hot smoothers should be avoided whenever possible. With the proper mixture and one which has been rolled while hot, the surface should be entirely closed up. Under unfavorable weather conditions, in order to close up the surface, it may be necessary in certain places to use hot smoothers. Care should be taken to see that these are not too hot; otherwise they will burn the pavement and scaling will eventually result. The inspector on the street should, whenever possible, keep an accurate account of the number of loads delivered. Knowing the number of pounds

of mixture per load and the weight per square yard, he can then check up the yardage which should have been laid with the material delivered on the street if it were raked to the proper thickness.

Inspection of Finished Work. If the inspection at the plant and street during the construction of the pavement has been adequate, the final inspection of the work will be chiefly confined to an examination of the contour and surface of the street. During this examination careful note should be made of whether or not the mixture has been thoroly compressed and is closed up on the surface. Where there has been no inspection during the manufacture and laying of the pavement, or where this inspection has been inadequate, defects will frequently develop in the pavement. Under these circumstances, it becomes necessary to examine the finished work in order to determine the reason for the defects or failures. In an inspection of this sort, careful note should be made of the condition of the surface and its contour. Frequently marked depressions occur where the pavement has been laid over a trench dug just prior to its construction, and in which the back-filling was not properly done. A thoro examination of the street will usually involve the cutting out of numbers of samples of the bituminous surface. These should be carefully marked as to location and a sufficient number of them taken to fairly represent the surface examined. They should be sent to a central laboratory for examination as to the percent of bitumen contained in them, the mesh composition and character of the mineral aggregate and the physical and chemical characteristics of the asphaltic cement used in the pavement. Wherever these samples are cut out, careful note should be made of the depth of the pavement at this point. In many instances it will also be necessary to cut thru the foundation to determine its character and thickness. Laboratory examinations of concrete foundations are usually not very valuable in determining the amount of cement which has been used in them, but a combination of physical and chemical tests of the foundation will often establish satisfactorily whether or not they have been defective. The method of examination used will, of course, have to be varied, depending upon circumstances and the character of the defects which have been developed.

Laboratory Equipment. The plant laboratory should be equipped with a set of standard sieves, 200, 100, 80, 50, 40, 30, 20 and 10-mesh, and a pair of sand scales; a stiff brush for cleaning the sieves, which should preferably be a small one with good, stiff bristles; a sand sampler; a set of screens for testing binder stone, 1/8, 1/4, 1/2 and 1-in; thermometers for use with the penetration machine and for testing the temperature of the paving materials; a penetration machine; a dishpan or other receptacle for holding water at the standard temperature, in which to immerse the asphalt cement samples which are to be tested; two trowels, one 4-in and the other 6-in; a 4-in wall brush; two wooden paddles; a roll of manila paper 12 in wide mounted on a stand provided with a cutting device, two iron pails and a gas or oil stove. This will be sufficient to carry out the simple tests required by the inspector. If chemical analyses are to be made, a much more elaborate equipment will of course be required.

17. Specifications for Construction

The following specifications were adopted in 1916 by the Am. Soc. Mun. Imp. At the conclusion of the specifications, comments and explanations pertaining to several sections of the specifications have been appended.

For sections covering materials, see Art. 12, and for sections covering maintenance, see Art. 22.

"1. General Description. Upon the foundation, prepared and laid as elsewhere herein specified, shall be laid the pavement proper. This shall consist of: (a) A binder course . . . in in thickness when compressed; and (b) an asphalt wearing surface . . . in in thickness when compressed.

"11. Binder, Preparation. The binder shall be composed of stone, or stone and sand, and asphalt cement of the character elsewhere herein specified and mixed in proper proportions. The stone, or stone and sand, and the asphalt cement shall be heated separately to such a temperature as will give, after mixing, a binder of the proper temperature for the materials employed. The stone when used must be at a temperature between 107° and 177° C (225° and 350° F). The asphalt cement and stone shall be thoroly mixed by machinery until a homogeneous mixture is produced in which all the particles are thoroly coated with asphalt cement.

"12. Binder, Laying. The binder mixture prepared in the manner above described shall be brought to the work in wagons covered with canvas or other suitable material and upon reaching the street shall have a temperature between 93° and 163° C (200° and 325° F). The temperature of the binder mixture within these limits shall be regulated according to the temperature of the atmosphere and the working of the binder. On reaching the street it shall at once be dumped on the concrete and then be deposited roughly in place by means of hot shovels, after which it shall be uniformly spread by means of hot iron rakes and then at once thoroly compacted by tamping or rolling. Tamping shall only be permitted in those places which are inaccessible to a roller. Rolling shall be carried on continuously at the rate of not more than 300 sq yd per hr per roller until a compression is obtained which is satisfactory to the Engineer. The thickness of the finished binder shall average . . . in and not more than 40% variation from the average thickness specified will be permitted at any one spot. The upper surface of the finished binder shall be parallel to the established grade for the finished pavement. The surface after compression shall show at no place an excess of asphalt cement and any spot showing such excess shall be cut out and replaced with other material. All binder that shows lack of bond or that is in any way defective or which may become broken up before it is covered with wearing surface must be taken up and removed from the street and replaced by good material, properly made and laid in accordance with these specifications, at the expense of the Contractor. No more binder shall be laid at any one time than can be covered by a day's run of the paving plant on surface mixture. Binder when laid shall be followed and covered with wearing surface as soon as is practicable in order to effect the most thoro bond between the binder and the wearing course. The binder course shall be kept as clean and as free from traffic as is possible under working conditions. If necessary, it must be swept off immediately before laying the wearing surface on it. No binder shall be laid when in the opinion of the Engineer the weather conditions are unsuitable or unless the concrete on which it is to be laid is, even tho damp, free from pools of water and has set a sufficient length of time.

"13. Binder, Requirements. The finished binder must contain 4 to 7% of bitumen soluble in cold carbon disulphide, from 15 to 35% of material passing a 10-mesh sieve, and from 20 to 50% of material passing a ½-in screen, the percentage of bitumen to be regulated in accordance with the mesh composition and character of the mineral aggregate of the binder, and the percentage of material passing a 10-mesh sieve to be regulated in accordance with the traffic conditions upon the street or streets to be paved.

"14. Wearing Surface, Preparation. The wearing surface shall be composed of sand, filler and asphalt cement of the character elsewhere herein specified and mixed in proper and definite proportions by weight. The sand and the asphalt cement shall be heated separately to such a temperature as will give, after mixing, a surface mixture of the proper temperature for the materials employed. The sand when used must be at a temperature between 135° and 204° C (275° and 400° F). The asphalt cement when used must be at a temperature between 121° and 177° C (250° and 350° F). The various ingredients shall be brought together and mixed for at least 1 min in a suitable apparatus until a homogeneous mixture is produced in which all the particles are thoroly coated with asphalt cement. The weights of all materials

entering into the composition of the wearing surface shall be verified in the presence of inspectors as often as may be required and the Engineer or his representatives shall have access to all parts of the plant at any time.

"15. **Wearing Course, Laying.** The surface mixture prepared in the manner above described shall be brought to the work in wagons covered with canvas or other suitable material and upon reaching the street shall have a temperature between 110° and 177° C (230° and 350° F). The temperature of the surface mixture within these limits shall be regulated according to the temperature of the atmosphere and the working of the mixture and the character of the materials employed. On reaching the street it shall at once be dumped on a spot outside of the space on which it is to be spread. It shall then be deposited roughly in place by means of hot shovels, after which it shall be uniformly spread by means of hot iron rakes in such a manner that after having received its final compression by rolling, the finished pavement shall conform to the established grade. The thickness of the finished surface mixture shall average . . . in. Not more than a 10% variation from the average thickness specified will be permitted in any one spot. Before the surface mixture is placed, all contact surfaces of curbs, manholes, etc, must be well painted with hot asphalt cement. After raking, the surface mixture shall at once be compressed by rolling or tamping, after which a small amount of cement shall be swept over it and it shall then be thoroly compressed by a steam roller weighing not less than 200 lb to the in width of tread, the rolling being carried on continuously at the rate of not more than 200 sq yd per hr per roller, until a compression is obtained which is satisfactory to the Engineer. Such portions of the completed pavement as are defective in finish, compression or composition, or that do not comply in all respects with the requirements of these specifications, shall be taken up, removed and replaced with suitable material, properly made and laid in accordance with these specifications, at the expense of the Contractor. Whenever so ordered by the Engineer, a space of 12 in next to the curb shall be coated with hot asphalt cement, which shall be ironed into the pavement with hot smoothing irons. No wearing surface shall be laid when, in the opinion of the Engineer, the weather conditions are unsuitable or unless the binder on which it is to be placed is dry. Excessive use of water on the steam roller when compressing the pavement will not be permitted. The finished pavement must be well protected from all traffic by suitable barricades until it is in proper condition for use.

"Note. When the pavement is laid alongside of brick or concrete gutters, street car tracks, manhole heads, or liners, it is recommended that the finished surface adjacent to them be left ¼ in high, in order to provide for subsequent compression by traffic and to avoid depressions which would otherwise be liable to occur at these points.

"16. **Wearing Course, Requirements.** The finished pavement shall show, upon analysis, a mesh composition and bitumen contents within the following limits, sieves to be used in the order named:

Bitumen	9.5 to 13.5%		
Passing 200-mesh sieve. Not less than	10%	Total passing 200, 100 and 80-mesh......Not less than	25%
Passing 80-mesh sieve	10 to 35%		
Passing 50-mesh sieve	4 to 35%	Total passing 50 and 40-mesh	15 to 50%
Passing 40-mesh sieve	4 to 25%		
Passing 30-mesh sieve	4 to 20%	Total passing 30, 20 and 10-mesh	10 to 35%
Passing 20-mesh sieve	4 to 12%		
Passing 10-mesh sieve	2 to 8%		
Passing 8-mesh sieve	0 to 5%		

"The minimum amount of bitumen shall be used only in mixtures containing the minimum total passing the 80-mesh. The percentage of bitumen must be increased above the minimum as the total passing the 80-mesh increases. On streets of very light traffic, when the Engineer has approved the use of a coarser sand or mixture than that specified for general use, the surface mixture must contain not less than 6% of mineral matter passing a 200-mesh sieve and not less than a combined total of 18% passing the 200, 100 and 80-mesh sieves. The maximum amount of 200, 100 and 80-mesh material will be regulated according to the kind of sand and asphalt used

and the traffic upon the street on which the pavement is to be laid, subject to the maximum requirements elsewhere herein specified under sand and filler. The above limits as to mesh composition and percent of bitumen are intended to provide for such permissible variations as may be rendered necessary by the raw materials used and by the character of the work to be done. The composition of the wearing surface may be varied within the limits above specified at the discretion of the Engineer, depending upon the kind of sand, filler and asphalt used and the traffic conditions upon the street or streets to be paved."

Comments and Explanations of sections of the Am. Soc. Mun. Imp. 1916 specifications follow:

Sections 11, 12 and 13. The points in these sections have been fully discussed under BINDER and THEORY.

Sections 14, 15 and 16. The points covered in these sections have been fully discussed under METHODS OF MANUFACTURE AND LAYING, and THEORY. As in Sect. 7, the limits given include both light and heavy traffic mixtures and are wider than should be applied to any particular set of conditions. Under the provisions of Sect. 16 the engineer may and should narrow the limits to suit the conditions prevailing upon the streets to be paved and the available local material.

18. Construction Cost Data

Costs vary greatly, depending upon the price of materials and labor. In some localities sand and stone are very expensive and in others they are quite cheap. Freight rates on asphalt and other raw materials from their point of production to the place where they are to be used are a very important item. Where the climate is favorable and the work can proceed uninterruptedly, the labor costs are much lower than in rainy climates where frequent shut-downs are necessary and fuel and time are required to drive off excess moisture from raw materials and from foundations. Concrete and grading costs are generally so well understood that they will not be entered into here, as each engineer is familiar with them in his own particular locality.

Example of Cost Calculation. For the purpose of showing a typical cost calculation, it will be assumed that the pavement to be laid consists of a 1½-in binder course and a 1½-in wearing course, and that the binder is to contain 5% of bitumen, 25% of sand and 70% of stone, while the wearing course is to contain 11% of bitumen, 15% of filler and 74% of sand. The asphalt cement is to consist of 90% of refined asphalt and 10% of flux and will contain 96% of bitumen. The prices of the various raw materials delivered at the plant are:

Refined asphalt	$18.00 per ton gross, 5% tare,
Flux, 15° B gravity	0.07 per gal, no tare,
Binder stone	1.25 per cu yd, 2600 lb,
Binder sand	0.90 per cu yd, 2500 lb,
Surface sand, coarse	0.90 per cu yd, 2500 lb,
Surface sand, fine	1.00 per cu yd, 2500 lb,
Filler	5.00 per ton, net weight,
Coal	4.50 per ton.

ASPHALT CEMENT. Allowing for tare, 1900 lb of refined asphalt will cost $18. Flux of 15° B gravity weighs 8.05 lb per gal and hence would cost 0.87 cents per lb.

1900 lb refined asphalt @ $18.00	$18.00
211 lb flux @ 0.87 cents	1.84
2111 lb asphalt cement	$19.84 = 0.94

cents per lb for the asphalt cement.

Binder. As the asphalt cement is only 95% pure bitumen, the binder will contain 5.26% (5% ÷ 95%) in order to bring its bitumen contents up to the specified amount. This will cause a slight change in the percentages of stone and sand in the mixture.

1 cu yd binder stone (2600 lb) @ $1.25......	$1.25	69.81%
0.37 cu yd binder sand (928 lb) @ $0.90.....	0.33	24.93%
196 lb asphalt cement @ 0.94 cents..........	1.84	5.26%
	$3.42	100.00%

The sand and asphalt cement will increase the bulk of the stone but very little. Allowing for inequalities in the concrete, the above amount of binder mixture should lay 26 sq yd of binder course averaging 1½ in in thickness. The cost of materials for the binder course will therefore be 13.2 cents (3.42 ÷ 26) per sq yd.

Surface. As the asphalt cement is only 95% pure bitumen, the surface mixture must contain 11.58% (11% ÷ 95%) in order to bring its bitumen content up to the required amount. This will cause a slight change in the percentages of sand and filler in the mixture. The sand is to be mixed in the proportion of three parts of coarse to one part of fine and will therefore cost when mixed $0.925 per cu yd. Filler at $5 per ton will cost 0.25 cents per lb.

1 cu yd sand...	2500 lb @ 92½ cents per cu yd..	$0.925	73.52%
Filler.........	507 lb @ 0.25 cents per lb.....	1.27	14.90%
Asphalt cement	393 lb @ 0.94 cents per lb.....	3.69	11.58%
Surface mixture, 3400 lb	....	$5.885	100.00%

A standard wearing course 1½ in thick after being compressed, will weigh 150 lb per sq yd. 3400 lb will therefore lay 22.7 sq yd, hence the cost of materials for the wearing course will be $0.259 ($5.885 ÷ 22.7) per sq yd.

Fuel. The average cost of fuel for the plant and street should not exceed 2 cents per sq yd at the figures given for coal. It varies somewhat with the type of plant used and the daily output, the larger plants being the more economical. At the plant it is used under the boilers and the sand driers and on the street in the fire wagon and roller.

Labor at Plant

One foreman..........................	$3.00 per day,
One engineer.........................	2.50 per day,
One drum fireman,....................	2.00 per day,
One mixer man........................	2.00 per day,
Eleven laborers, @ $1.75	19.25 per day,
One night watchman...................	1.50 per day,
	$30.25 per day.

The above force with a suitable plant ought to be able to turn out sufficient material for not less than 800 sq yd of finished pavement per day of 10 hr. This assumes the plant to have a daily capacity of 1200 sq yd of surface or 2400 sq yd of binder. Plants vary very greatly in their output and the number of men required to work them, some being much more economical of labor than others. On this basis the plant labor should not cost more than 3.78 cents (30.25 ÷ 800) per sq yd for the finished pavement. Overtime, delays due to bad weather, and other causes usually run this figure up to from 4 to 5 cents per sq yd of finished pavement.

LABOR AT STREET

One foreman	$3.00 per day,
Three rakers @ $2.50	7.50 per day,
Two tampers @ $2.50	5.00 per day,
One roller engineer	4.00 per day,
Three shovellers @ $1.75	5.25 per day,
One cement sweeper	1.25 per day,
One fire wagon man	1.75 per day,
One laborer	1.50 per day,
One night watchman	1.50 per day,
	$30.75 per day.

The above force should easily handle and lay 800 sq yd of finished work per day of the thickness specified. On this basis the street labor would cost 3.84 cents ($30.75 ÷ 800) per sq yd of finished pavement, but, owing to delays, etc, this will usually run from 4.5 to 5.5 cents.

HAUL. Assume the average haul to be 2 miles and that each wagon will hold 5000 lb of mixture and that wagons and teams cost $5 per day. With this length of haul a wagon should average five round trips per day of 10 hr, during which it would carry 25 000 lb of material at a cost of $5,

25 000 lb of binder would lay	179 sq yd 1½ in thick,
25 000 lb of surface would lay	166 sq yd 1½ in thick.

The cost of haul per sq yd would therefore be:

Binder	2.8 cents ($5 ÷ 179)
Surface	3.0 cents ($5 ÷ 166)
Total	5.8 cents

ADMINISTRATION. When work of any magnitude is being carried on a general superintendent and a bookkeeper are required together with an office. The expense of this in a town where a plant of the size assumed would work economically would be approximately as follows:

General superintendent	$6.00 per day,
Bookkeeper	2.00 per day,
Office rent	1.00 per day,
Sundries	1.00 per day,
	$10.00 per day.

This would amount to 1.25 cents per sq yd ($10 ÷ 800) which should be increased to 2 cents to allow for delays.

GENERAL EXPENSE. Under this item would come expense of securing contract, promotion expense, head office expense, etc. This is such an uncertain quantity that it is hard to figure, but for ordinary conditions 5 cents per sq yd should cover it.

GUARANTEE BONDS AND MAINTENANCE FOR 5 YEARS. This again varies greatly with traffic conditions, etc, but will probably average 10 cents per sq yd for the entire period.

INTEREST ON INVESTMENT. Plant and street tools for the output under discussion would probably cost not less than $15 000. The interest on this at 6% would amount to $900 per annum. Assuming 180 full working days in a year, this would amount to $5 per day or ⅝ cents per sq yd. These conditions, again, vary so greatly as to make it impossible to estimate them accurately, but on the average 1 cent per sq yd should be a

fair charge. Larger plants with increased output would cost much more than $15 000, but the larger yardage of pavement laid with them would offset this. In many localities the conditions will permit of more than 180 full working days per annum.

REPAIRS AND DEPRECIATION. Ten per cent depreciation per annum and a yearly allowance of $900 for repairs would be reasonable for the conditions assumed in making this estimate. This would make a total of $2400, or $13.33 per working day for 180 days, which is equivalent to a cost of 1.66 cents per sq yd, say, 2 cents, per sq yd.

The total cost, exclusive of profit, for the pavement and conditions assumed is therefore:

Binder, materials	13.20 cents per sq yd,
Surface materials	25.90 cents per sq yd,
Fuel	2.00 cents per sq yd,
Labor at plant	4.50 cents per sq yd,
Labor at street,	5.00 cents per sq yd,
Haul	5.80 cents per sq yd,
Administration	2.00 cents per sq yd,
General expense	5.00 cents per sq yd,
Guarantee and maintenance for 5 years	10.00 cents per sq yd,
Interest on investment	1.00 cents per sq yd,
Repairs and depreciation	2.00 cents per sq yd,
Total cost per sq yd	76.40 cents per sq yd.

Character and Cost of Sheet-Asphalt Pavements in 1915 in Several Cities

From *Engineering and Contracting*, April 5, 1916

City	Square Yards	*Price per Square Yard	Guarantee Years	Wear'g Course Thickness, Inches	Binder Course Thickness, Inches	Concrete Foundation	
						Thickness, Inches.	Proportions
Boston, Mass.	33 928	$2.25†	5	1½	1½	6	1 : 3 : 7
Providence, R. I.	27 628	1.87	5	1½	1½	6	1 : 3 : 6
Albany, N. Y.	42 452	1.76	5	2	1	9	1 : 3 : 6
Bor. of Manhattan New York City	51 169	1.82	5	2	1	6	1 : 3 : 6
Camden, N. J.	31 796	1.90	..	2	1	6	1 : 3 : 6
Harrisburg, Pa.	38 551	1.80	5	2	1	6	1 : 3 : 7
Baltimore, Md.	239 912	1.57†	5	1½	1½	6	1 : 3 : 6
Cincinnati, Ohio	29 732	2.42	5	1½	1½	6	1 : 3 : 6
Chicago, Ill.	854 681	1.75†	5	2	1½	9½	1 : 3 : 6
Detroit, Mich.	26 476	3.02	10	2	1½	6	1 : 3 : 6
Milwaukee, Wis.	227 833	1.90†	5	2	1	6	1 : 3 : 6
Fort Dodge, Ia.	23 445	1.69	5	2	1	5	1 : 3 : 5
Washington, D. C.	35 745	1.78	5	1½	1½	6	1 : 3 : 7
Greensboro, N. C.	48 100	1.50	..	1½	1½	5	1 : 3 : 6
Columbia, S. C.	51 532	1.86	5	2	1½	5	1 : 3 : 5
Lexington, Ky.	27 170	2.00	5	2	1	6	1 : 3 : 6
New Orleans, La.	37 820	2.25	5	1½	1½	6	1 : 3 : 5
Salt Lake City, U.	66 165	1.85†	5	1½	1½	6	1 : 3 : 6
Oakland, Cal.	57 649	1.90†	..	1½	2	6	1 : 3 : 6
Portland, Ore.	4 285	1.54†	..	2	1	5	1 : 3 : 6

* Price covers pavement, foundation, and preparation of subgrade.
† Does not include preparation of subgrade.

The general scheme of this cost calculation has been purposely made somewhat elaborate to show how all the various elements of cost may be figured. Where some of these elements are not involved they may be readily eliminated from the general scheme. Variations in the price of labor and materials will not involve any variation in the form of the calculation. It should be borne in mind that under certain conditions of large ouput, short haul and low maintenance cost, these figures may be considerably reduced. Where the price of materials is higher the cost will be correspondingly increased. The cost shown in the above calculation only covers binder and surface. Grading, foundation, curbing, manholes, and extra work are not included in it.

General Cost Data. Owing to the variation in the price of raw materials and the traffic conditions, it is impossible to give an average cost for standard sheet-asphalt paving construction which can be considered as authoritative or of great value. Exclusive of curbing and extra work, the average cost thruout the United States for a sheet-asphalt pavement, consisting of 6 in of concrete, 1½ in of binder and 1½ in of wearing surface, is probably about $1.80 per sq yd including grading to an average depth of not over 4 in. As illustrating the different conditions affecting prices, the foregoing table is given.

MAINTENANCE

19. Causes of Failure

The proper maintenance of a sheet-asphalt pavement involves the making of such repairs to it from time to time as are necessary in order that it may continue to render efficient service as a safe and smooth roadway or street.

The deterioration which eventually renders these repairs necessary commences as soon as the pavement is laid and may be broadly classified under the following heads: (1) Defects due to the wear and tear of traffic; (2) defects caused by the deterioration, thru age and exposure of the bituminous cementing material used; (3) defects in construction.

Traffic Deterioration. Under traffic the surface of the pavement is abraded and gradually wears off and the mineral particles exposed on the top are more or less crushed and broken. Where these particles are large, this crushing action is plainly noticeable, but with the smaller particles of sand it is hard to detect it. Under heavy traffic and unfavorable weather conditions, these crushed grains become active centers of disintegration. The crushed particles are not bound together by the asphalt cement and are soon swept away. The holes thus made in the pavement serve to retain the moisture and the edges of the holes are eventually more or less broken down, thus enlarging the hole. This condition reproduced all over the surface tends to make it wear away much more rapidly than would otherwise be the case. The effect of this action, which at first glance appears trivial, has been so well established by years of investigation and experience that it has become axiomatic in the paving industry that the heavier the traffic the finer must be the particles composing the mineral aggregate. In hot weather, when the pavement is plastic, the abrasion of the surface is much less than in cold weather, when the pavement is hard and possesses but little plasticity. In hot weather the calks on horses' shoes sometimes mark up the pavement to a very considerable extent, but the subsequent action of vehicular traffic wears these marks out almost completely. Nevertheless, in a community unaccustomed to sheet asphalt-

pavements, the appearance of these calk marks in a new pavement is always regarded as an ominous sign presaging its speedy destruction and failure. As a matter of fact, if the pavement, especially when newly laid, were not soft enough to show these marks it would be an almost infallible sign that the asphalt cement used in it was too hard and that the total life of the pavement would be less than if a softer asphalt cement had been used. Traffic on a pavement always compresses it and increases its density, and for this reason a two-year-old pavement will always mark up less than a new one. The pressure per square inch exerted by the comparatively narrow tire of a heavily loaded vehicle is much greater than that exerted by the heaviest steam roller used in the laying of sheet-asphalt pavements. Even if this were not the case, the kneading action produced by narrow tires passing many times over the surface would always give greater compression than could be obtained by the action of the broad tires of a steam roller.

When the traffic is confined to a comparatively narrow space and is always in the same direction, a distinct pushing force is exerted on the pavement. Whenever the pavement lacks inherent stability, due to an improper mineral aggregate or bitumen which is lacking in cementing value from natural causes or the rotting action of gas or water, or a combination of these defects, very distinct waves or bumps will be produced by the action of heavy traffic. These waves sometimes occur in recently laid pavements in which the asphalt cement used was of the highest quality, but in such cases will usually be confined to a few places. Investigation will almost always show defective binder in these spots, or too soft an asphalt cement, or too great a thickness of pavement owing to an error in the grade of the concrete. A paving mixture, designed to have proper stability when laid 2 in thick, will often fail in this respect when laid 4 in thick, which is the explanation in the case last cited. Too soft an asphalt cement will also reduce the stability of a pavement. Once these waves appear, they are aggravated by traffic passing over them. The wheel of each vehicle rises to the crest of the wave and then drops down with considerable force into the adjacent depression. The plastic pavement in this way is continually displaced at the low spots and shoved up at the high spots until in many instances the concrete will be exposed at the bottom of the depression. Similar depressions are produced by setting manholes too high above the surrounding pavement. Vehicles drop off these high manhole covers onto the pavement and soon pound it out of place. It is better to set all manholes slightly below the grade established for the finished pavement.

Waves are much less liable to appear in those portions of the pavement which are subjected to cross traffic; that is, in which the traffic does not always move in the same direction. This is usually the case at street intersections, and, if properly constructed, the pavement in these locations almost always lasts longer than in any other part of the street. It has been seriously suggested that in order to increase the effective life of pavements, the direction of the traffic in the afternoon should be the reverse of that in the morning, but the resulting confusion would probably more than offset the gain from such a procedure. Car tracks in a street paved with sheet-asphalt may cause the pavement to deteriorate very rapidly. Unless the rails are very heavy and laid on an adequate foundation, they will vibrate excessively when cars pass over them. This is especially the case where tracks designed for light city or town cars are subsequently

called upon to carry heavier cars or cars of the interurban type. Not only will the vibration be excessive, but the rails will frequently sink below the level of the pavement and leave depressions where the water will collect. To prevent the vibration from being communicated directly to the sheet-asphalt, rows of paving blocks or bricks are frequently placed along the rails, altho in many cases the sheet-asphalt is brought up directly to the rails. When the vibration is excessive, the sheet-asphalt pavement crumbles or cracks in a very short time and leaves an opening for surface water to enter between the wearing surface and the concrete foundation, thus permitting the rotting action elsewhere described to take place.

Effect of Ageing and Exposure. All bituminous materials used in paving work deteriorate upon exposure to the elements and to the rotting action of escaping gas, water and street liquids. The lighter oils contained in them gradually volatilize, thus hardening the remaining bitumen. As the hardening process goes on, the pavement loses its plasticity and wears away with increased rapidity. Eventually the bitumen loses its elasticity and the pavement cracks. The edges of these cracks crumble away and the cracks become sufficiently wide to be plainly felt by vehicles passing over them. The bumping action previously described in connection with waviness is produced and adds to the rapidity with which crumbling takes place. In order to guard against this and prolong the effective life of the pavement, the asphalt cement used in its construction is made as soft as possible without rendering the pavement too mushy when new. The extent to which this can be carried depends upon the grading and character of the sand employed. With a well graded sharp sand and plenty of filler, a much softer asphalt cement can be used than with a poorly graded or rounded sand. This is due to the greater inherent stability of the former type of sand. It is obvious that a mineral aggregate which when dry strongly resists displacement will permit the use of a comparatively soft asphalt cement. Modern traffic conditions have in this particular respect come to the aid of the pavement makers. Automobiles in their passage over the pavement are continually dropping a certain amount of oil on its surface which is very evenly distributed by the large number of vehicles passing over it. This oil is gradually absorbed by the pavement and thus softens the bitumen and counteracts to a large extent the hardening action of time upon it. This is very clearly shown in a certain pavement in Chicago, which, prior to the passage of any considerable number of automobiles over it, about 1910, was so hard and badly cracked as to have practically reached its limit of usefulness. The street in question subsequently developed into an automobile center with the result that the pavement was softened up by the dropping of oil upon it to such an extent that, in 1915, it was still giving satisfactory service. Fifth Ave., New York City, is a somewhat similar case.

Some asphalts are more easily rotted by water action than are others. With such asphalts it is more than ever necessary to make the pavement as dense as possible to prevent the water from getting into it. Generally speaking, with all asphalts the wetter the climatic or other conditions, the denser and richer in bitumen should the mixture be made. The action of water upon a pavement may take place from the surface downward or from the bottom upward. The latter action is the more serious and the harder to guard against. The top surface is always compressed to its maximum density by the action of traffic, and if it has sufficient crown and grade to let the water run off and is kept clean so that

it will not be covered by a layer of wet mud for long periods, but little deterioration will take place. Where water is allowed to remain in the gutters, the rotting will frequently be very rapid and this will be still more marked if, as in some towns, the dirty wash water from houses is discharged into the gutters. Too frequent washing of a pavement with water at a high pressure is also bad, as the abrasive action of such a jet is very considerable and acts in the same way as the stream from a hydraulic nozzle. In a number of cases water finds its way between the wearing surface of the pavement and the concrete foundation. This may be due to the geological formation of the subsoil strata (and it must be remembered that concrete is not waterproof, especially the type used for foundation work) or the water works its way down between car tracks and the abutting pavement, or thru faulty gutter construction, etc. Under such conditions, it has little or no chance to evaporate or drain off and attacks the pavement at its weakest point, that is, where the compression is the least. It gradually destroys the life of the bitumen and renders it incapable of cementing the grains of sand together. This action progresses upward thru the pavement and in some cases is not apparent until only a top shell of good pavement remains. Depending upon the conditions, this action usually manifests itself by shoving and waviness of the pavement at the point where the rotting has taken place. Owing to the loss of the cementing power of the bitumen, the stability of the pavement has been lowered so that it can no longer withstand the shoving action of traffic previously described. If the pavement is cut thru at this point, the white sand grains will be plainly apparent and the whole mass can be readily disintegrated between the fingers. As soon as the rotting action reaches the surface, the pavement is quickly worn away by traffic and a hole is produced.

Gas leaks produce a very similar result and the gas sometimes travels a long distance from the point of leakage before it actually comes in contact with the pavement.

Another cause for the deterioration of sheet-asphalt pavement is lack of traffic. Pavements laid on outlying residence streets and culs-de-sac with little or no traffic, crack much more quickly than if they were subjected to a moderate traffic, which appears to be necessary to keep the life in the pavement. This is probably due to the fact that the surface is not in such cases kept at the maximum density by the action of traffic and gradually becomes porous, thus facilitating the evaporation of the lighter oils and also to the fact that the kneading action of traffic, like the continual use of a rubber band, tends to keep the life, so to speak, in the bitumen and equalizes the stresses set up by contraction and expansion.

Defects in Construction. These may perhaps be more clearly understood by a general discussion of the principles involved and the correct way of carrying them out and coincidentally calling attention to the particular defects arising from marked departures from standard practice.

Unless the foundation is rigid and of sufficient strength to carry the weight of the traffic passing over the finished pavement, no sheet-asphalt wearing surface will give satisfactory service. Being plastic at all normal temperatures, the wearing surface will not bridge over any depressions formed by the sinking or failure of the foundation, but will sink with it. The principles governing good foundation work and design need not be considered here except to say that the subgrade must be well rolled and compacted in the first place and that good concrete of sufficient strength and thickness should then be put in place and allowed to set before any

binder or wearing surface is put upon it. Assuming that the subgrade has been properly rolled and that the concrete is of the proper thickness and quality, the first point of importance is to see that it is laid to grade. If it is too high in places, the thickness of the binder and wearing surface must be reduced in order that the surface of the finished pavement may conform to the established grade. Any marked diminution in the thickness of the wearing surface will, under heavy traffic, considerably reduce the life of the pavement. On the other hand, if the concrete is laid too low, the thickness of the binder and wearing surface will have to be increased. Within limits, this is not objectionable if the increased thickness is not carried to such an extent as to affect the stability of the pavement, otherwise it will tend to roll and push out of shape under traffic, as previously described. It is usually considered better practice to leave the surface of the finished concrete somewhat rough in order that the binder may key into these depressions and still further resist the shoving action of traffic. After the concrete has been put in place, ample time should be allowed for setting, and this will vary with the weather conditions. Concrete laid in freezing weather will apparently set up when in reality it has frozen. When the hot binder and surface mixture are placed on frozen concrete, the latter is thawed by the action of the heat and becomes mushy and has not sufficient strength to support the weight of the steam roller. Under such circumstances it is impossible to properly compress the hot mixture. In addition to this, the water set free by the thawing of the concrete is forced into the mass of hot material and more or less of it remains entrained in the mass.

In most forms of construction, a binder is laid directly on top of the concrete, altho this is sometimes omitted and a paint consisting of asphalt dissolved in naphtha is applied directly to the dry surface of the concrete and the wearing mixture laid directly on this.

A close binder properly made and laid will be superior in many respects to the mixtures which have been laid on a large number of country highways and will carry a fair amount of traffic for a considerable time without suffering any serious damage. Poor binder will break up very easily, sometimes it can be kicked up, and the hauling of the hot surface mixture over it will damage it very seriously. Surface mixture laid on a binder of this kind which has been badly broken up might almost as well be laid on loose broken stone and will not give satisfactory service under heavy traffic.

Lack of compression will produce an unsatisfactory foundation for the wearing surface, and, as previously mentioned, binder which is too cold or made with too hard an asphalt cement or an insufficient quantity of asphalt cement can not be properly compressed into a dense, tough mass. In hauling the binder to the street over long distances or in very cold weather, it may become chilled below the danger point.

Before laying the surface mixture on the finished binder course, the latter should be dry and swept clean of dirt; otherwise the layer of wearing surface will not adhere properly to it. When delivered upon the street, the mixture should be of such a temperature that it can be properly compressed and should be evenly spread by means of hot iron rakes. In many cases the loads of hot surface mixture are dumped directly upon the spot over which they are to be spread. This is bad practice, as the men trample upon it while shovelling and raking it and the rakes do not thoroly loosen up this trampled material when passing over and thru it. Altho the mixture is raked to a uniform surface and apparently even thickness before it

is rolled, those portions which have been trampled on before and during raking are really covered with a greater quantity of surface mixture than those portions which have not been trampled on and which are covered wholly with what might be termed loose or fluffy mixture. When the roller has completed its work there will, therefore, be a slight unevenness in the finished surface. Under light traffic this would make no appreciable difference, but under very heavy traffic the slight pounding action resulting from this condition would be detrimental and lead to uneven wear of the pavement. Proper and thoro compression of the finished mixture is very essential as this produces a pavement which in its earliest stages is fit to sustain the heaviest traffic. It is always questionable whether portions which are very lacking in compression will be ground out or eventually consolidated. Under unfavorable conditions the chances are strongly in favor of their being ground out. In those portions of the pavement which are inaccessible to the roller, compression is affected by the use of hot smoothers or tampers, or both. If properly handled, the desired results will be obtained, but if used too hot, they will burn the pavement and cause it to scale or grind out. Hot smoothers particularly are dangerous tools to put in the hands of incompetent or careless workmen.

The practice of painting the edge of the joint with hot asphalt cement is not to be recommended, as, unless extreme care is exercised, too much asphalt cement will be used and that portion of the pavement will be too rich in bitumen and consequently softer than the rest, which will result in uneven wear and possibly shoving. Great care should be taken not to have any hump or depression when the joint is made.

A Summary of the Chief Defects and Failures met with in practice and the contributing causes is given below.

Cracking is due to cracking of the concrete base; hardening of the asphalt cement thru age; use of too hard an asphalt cement; use of an unsuitable asphalt cement; too little bitumen in the surface mixture; insufficient compression; lack of traffic; improperly constructed joints; extreme and sudden changes in temperature; vibration of street-car rails.

Disintegration of Surface is due to defective base; unsuitable mineral aggregate; insufficient bitumen in mixture; insufficient compression; use of too hard an asphalt cement; use of overheated mixture; burning due to use of excessively hot smoothers; action of water; action of illuminating gas.

Waviness is due to use of an unsuitable sand; use of too soft an asphalt cement; unstable binder; lack of stability in mixture; too great a thickness of mixture; projecting manholes; action of water; action of illuminating gas; uneven raking; too much bitumen in mixture; excessively heavy traffic in one direction over a limited area.

Scaling is due to too coarse a mineral aggregate; too hard an asphalt cement; action of water; accumulation of mud; too little bitumen; excessively heavy traffic.

20. Methods of Repairing

Repairing should be carried on within a reasonable time after defects first make their appearance. If this is neglected, deterioration proceeds much more rapidly than would otherwise be the case. Holes and depressions are increased in size by the passage of vehicles over them and water accumulates in them, accelerating disintegration.

Two distinct methods of repairing are in general use: (1) The pavement is cut out and removed down to the concrete and replaced with new binder

and surface; (2) the upper portion of the surface is first heated by suitable appliances and a thin layer of it removed by rakes and shovels. Immediately thereafter and while the remaining pavement is still warm, a comparatively thin layer of new hot surface mixture is spread over it and raked and compressed in the usual manner followed in the construction of new pavements.

Pavement Cut Out and Replaced. The first method is so simple that but little description of it would appear to be necessary. The defective pavement is cut up into pieces sufficiently small to facilitate its removal and pried up with crowbars if necessary. The adjacent edges of the old pavement are trimmed up with an asphalt cutter and sparingly painted with hot asphalt cement to insure a proper bond between the old and new portions. Under favorable conditions and when the pavement being repaired is not too old and hard, this painting with asphalt cement may well be omitted. All loose debris is removed down to the concrete and a new binder course and wearing surface is then laid in exactly the same manner as when constructing a new pavement. This method should always be employed in filling up holes and depressions or wherever the defective pavement is in such shape as to necessitate its complete removal, as in the case of rotting from the bottom upward and waviness, defective binder or foundation, etc.

Heating Surface of Pavement and Adding New Material. The second, or surface heater method of repair, is conducted as follows: The surface heater is placed over the defective pavement and put in operation. Superheated steam, hot air or flame is then brought in contact with the surface and is allowed to remain there until the pavement has been softened to the required depth, usually from $\frac{3}{4}$ to 1 in. The heater is then withdrawn and placed on the next spot to be repaired and the burned material completely removed. The space thus left is immediately filled with new hot surface mixture which is spread, raked and finished in the usual manner. Care must be taken to completely remove all burnt material down to such a depth that the new surface after compression will be not less than $\frac{3}{4}$ in in thickness. Skin patching of less depth than this has not proven satisfactory. In order that repairs made by this method will give satisfactory service, it is essential that the remainder of the old pavement which serves as a foundation should be sound and in good condition and free from water rotting. It is not applicable to the class of repairs rendered necessary by defective binder, or foundation, or water, or gas rotting. When it becomes necessary to resurface, wholly or in part, a pavement which has become too hard thru age to give satisfactory service, the surface heater method gives very good results and is much cheaper than a complete removal of the old pavement down to the concrete. By applying the hot new surface mixture to the remaining portion of the old pavement while the latter is still hot from the action of the heater, a satisfactory union between the old and new work can readily be obtained, provided that the hardening of the old pavement has not been allowed to proceed so far that it is impossible to soften it by the application of heat. Cracks may in most cases be more successfully repaired by this method than is possible in any other way. The repairing of cracks satisfactorily is a very difficult matter. If they are cut out and new material put in, this results in the formation of two joints approximately parallel to the original crack. If the pavement being repaired is old and hard, it is difficult to establish a good bond between the old and new portions, and unless this is accomplished, two

cracks will shortly appear where only one existed before. This is especially the case where long cracks make their appearance at considerable intervals and in many instances these had better be left until they become sufficiently wide or numerous to render more or less extensive resurfacing necessary at the places where they occur.

21. Guarantees

In the early days of the industry 15-year guarantees were common. This was subsequently cut to 10 years and finally to 5 years, which last is the most satisfactory. Under fairly heavy traffic, a 10 or 15-year guarantee involves so many uncertainties that in order to protect himself from financial loss a contractor must bid a high price. The character of the traffic may completely change in this period and the type of construction originally employed be absolutely inadequate to meet changed conditions. Long guarantees usually result in very high prices and severely handicap the smaller contractor. The large concern with a number of streets in different localities to maintain is able to apply the excess revenue from the maintenance of some of their streets to offset unexpectedly heavy drains on others. Bonding companies soon perceived the fallacy of acting as sureties on long term maintenance. The many considerations entering into the construction of a sheet-asphalt pavement are not well known to most city officials and they are therefore unable thoroly to supervise the laying of it. Without thoro and trained inspection they are at the mercy of the contractor, who himself is often more or less ignorant of the principles of the art. A guarantee for a moderate period, say 5 years, is therefore a useful protection provided the bonding company and the contractor live up to their obligations. Past experience conclusively shows that even this safeguard is often woefully lacking in real value and that the only proper method is to have competent supervision of the pavement while it is being manufactured and laid. Many of the larger cities have organized their own inspection departments and the smaller ones who can not afford this expense are employing inspecting engineers.

22. Specifications for Maintenance

The following specifications were adopted in 1916 by the Am. Soc. Mun. Imp. At the conclusion of the specifications, comments and explanations pertaining to several sections have been appended.

"17. **Condition at Expiration of Guarantee.** In addition to the proper maintenance of the pavement during the period of guarantee, the Contractor shall, at his own expense, just before the expiration of the guarantee period, make such repairs as may be necessary to produce a pavement which shall:

a. Have a contour substantially conforming to that of the pavement as first laid and free from depressions of any kind exceeding ½ in in depth as measured between any two points 3 ft apart on a line conforming substantially to the original contour of the street.

b. Be free from cracks or depressions showing disintegration of the surface mixture.

c. Contain no disintegrated surface mixture.

d. Not have been reduced in thickness more than ⅜ in in any part.

e. Have a foundation free from such cracks or defects as will cause disintegration or settling of the pavement or impair its usefulness as a roadway.

"18. **Repairing.** Repairs, except as provided for below, shall in all cases be made by cutting out the defective binder and wearing surface down to the concrete and replacing them by new and freshly prepared binder and wearing surface made and laid in strict accordance with these specifications. Whenever any defects are caused by the failure of the foundation, the pavement, including such foundation, shall be taken

up and relaid with freshly prepared material made and laid in strict accordance with these specifications. In all cases the surface of the finished repair shall be at the grade of the adjoining pavement and in accordance with the contour of the street.

"The surface heater method of repairing may be used only in those cases where the repairs are not rendered necessary by: (1) Failure of concrete; (2) failure of the binder; (3) failure caused by the disintegration of the lower portion of the wearing surface. Whenever the surface heater method is employed, all defective surface shall be removed before replacing it with new material. In all cases the old surface shall be removed to a depth of not less than ¼ in and the new surface must, when compressed, be not less than ½ in in thickness. The heat shall be applied in such a manner as not to injure the remaining pavement. All burnt and loose material shall at once be completely removed and, while the remaining portion of the old pavement is still warm, shall be replaced by new and freshly prepared wearing surface made and laid in strict accordance with these specifications.

"19. NOTE TO ENGINEERS. Filler. As Portland cement is more expensive than limestone dust, the specification should distinctly state which kind of filler is desired.

"Binder. The following clause has been suggested as being descriptive of the practice in some cities. The committee, however, does not feel like recommending it in a general specification. If this clause is incorporated in the specifications it should be clearly stated whether or not the practice described therein will be permitted by the City Engineer.

"With the permission of the City Engineer, not to exceed 20% of crushed old asphalt surface mixture of suitable character may be used in combination with the binder stone, provided that such mixture produces a binder complying in all respects with the requirements of these specifications."

Comments and Explanations of sections of the Am. Soc. Mun. Imp. 1916 specifications follow:

Section 17. This is intended to insure that the pavement at the expiration of the guarantee period shall be handed over to the city in a serviceable condition. It is not intended to place upon the contractor the burden of repairing defects other than those caused by defective workmanship or materials or ordinary wear and tear.

Section 18. This specifies the manner in which repairs shall be made and these are discussed at length under METHODS OF REPAIRING.

Section 19. This suggests a clause permitting the use of crushed old surface mixture in the binder mixture instead of sand. The cold crushed material should be added to the hot stone after it has passed thru the heating drums and then be mixed with it until both materials have reached approximately the same temperature. If the surface mixture were passed thru the ordinary drying drums with the sand it would be burnt and become unfit for use. If desired, drums or heating devices of special construction to avoid overheating may be used for heating the surface mixture. Only a surface mixture of suitable character shall be used.

ROCK ASPHALT PAVEMENTS

GENERAL DATA

23. Description and Historical Development

General Description. Rock asphalt pavements differ from sheet-asphalt pavements in that the mineral aggregate has been impregnated by nature with a bituminous cementing material. The mineral aggregate consists of sand or finely divided limestone and will generally all pass a 10-mesh sieve. They are usually laid directly on a concrete foundation, the binder course used with sheet-asphalt pavements being generally omitted.

History. European rock asphalt pavements have a mineral aggregate composed of finely divided limestone impregnated with a very soft bitumen. Commercial deposits of this material occur in France, Italy and Germany and have been known since 1712. The Val de Travers deposits in Switzerland have been worked since about 1720, those at Lobsann, Germany,

since about 1735, and those at Seyssel, France, since about 1797. Count de Sassenay in 1802 greatly improved the old and very crude method of mining and handling the material. At first only an asphalt mastic was manufactured and this was produced by enriching the ground rock with additional bitumen extracted from rock obtained from the same deposit. The rock asphalt mastic so produced was used for paving floors, sidewalks and, finally, streets. In 1834 mastic pavements met with some success in Lyons, France. About the same date mastic began to be used extensively in Paris for sidewalks. It was not until 1854 that the compressed rock, but not in the form of mastic, was used in street pavements and in that year Leon Malo paved the Rue Bergere in Paris with it. This proved successful and its use spread rapidly. In 1869 Threadneedle St., in London, was paved with Val de Travers rock asphalt and in 1871 rock asphalt pavements were laid in Geneva and Berlin. Shortly thereafter similar pavements were laid in New York City, Boston, Buffalo, New Orleans, La., and other American cities, but the high cost of importing the rock asphalt from Europe and the invention of the American type of sheet-asphalt pavements, which could be laid at a much lower cost, eventually led to its practical abandonment in the United States as a street pavement. Large quantities of mastic for flooring, waterproofing and sidewalk work are, however, still imported. Numerous bituminized sand and limestone rock deposits are found in the United States altho the former predominate. It is probable that the bituminized sands at Carpinteria, near Santa Barbara, Cal., were the first ones used for paving roadways in the United States and that they were employed about 1865. Bituminous limestone deposits are found in the United States in Oklahoma, Texas and Utah, and bituminous sandstones are found in Kentucky, Oklahoma, California, Texas and Utah. Many of them have been utilized for paving purposes but generally only in the immediate neighborhood of the deposits, as, except within a limited distance, they could not compete in price with a sheet-asphalt pavement.

24. Characteristics

Rock asphalt pavements, when properly constructed, closely resemble sheet-asphalt pavements in many respects. They are smooth, non-productive of dust, almost noiseless, waterproof, non-absorbent and easy to clean. Limestone rock pavements are smoother and more slippery than sheet-asphalt pavements. They do not soften up to the same extent in hot weather and the best type will probably sustain a slightly heavier traffic. Some of the heaviest traffic streets in cities in Europe are paved with them. Sandstone rock pavements when containing a properly graded mineral aggregate are practically identical in appearance and texture to sheet-asphalt pavements. Most natural deposits are impregnated with a soft bitumen and their mineral aggregate is not well graded. Under such conditions they mark up excessively in hot weather and are very liable to displacement under traffic and their use has been chiefly confined to light traffic streets.

Foundations should be the same as for sheet-asphalt pavements.

MATERIALS

25. Bituminous Limestones and Sandstones

Bituminous Limestones. Those obtained from Europe are more evenly impregnated with bitumen than are those found in the United States and

compact better and much more readily. It has been suggested that the Continental limestone matrix consists of the remains of marine organisms, which may account for this. Most of the American limestone rock contains particles of hard crystalline calcite which has not been impregnated with bitumen. The mesh composition of the European rock asphalts given in the following table represents the material as it reaches the United States after pulverization.

Table II.—European Bituminous Limestones

	1	2	3	4	5	6
Bitumen	6.1%	8.7%	8.5%	10.0%	9.8%	7.5%
Passing 200-mesh	42.9%	47.3%	37.5%	40.0%	35.2%	17.5%
Passing 100-mesh	9.0%	10.0%	15.0%	12.0%	17.0%	25.0%
Passing 80-mesh	6.0%	6.0%	12.0%	8.0%	11.0%	20.0%
Passing 50-mesh	7.0%	9.0%	14.0%	10.0%	14.0%	15.0%
Passing 40-mesh	8.0%	5.0%	4.0%	7.0%	9.0%	8.0%
Passing 30-mesh	8.0%	5.0%	4.0%	6.0%	2.0%	3.0%
Passing 20-mesh	7.0%	5.0%	3.0%	4.0%	1.0%	2.0%
Passing 10-mesh	6.0%	4.0%	2.0%	3.0%	1.0%	2.0%
	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Carbonate of lime	91.3%	87.1%	88.4%	88.2%	75.2%	80.0%
Carbonate of magnesia	Trace	0.9%	Trace	0.9%	13.5%	0.5%
Consistency of impregnating bitumen	Very soft	Very soft	Very soft	Very soft	Very soft	Very soft

(1) Seyssel, France; (2) Mons, France; (3) Val de Travers, Switzerland. (4) Ragusa, Sicily; (5) Sicula, Sicily; (6) Vor Wohle, Germany.

The bitumen contents of these rocks varies considerably in different portions of the deposits and the above figures represent the average as shipped to this country. Until the necessity was realized for blending materials from different parts of the deposit so as to produce a uniform product, many failures resulted.

Table III.—American Bituminous Limestones

	1	2	3	4	5
Bitumen	4.6 to 12.0%	3.0 to 7.0%	3.5 to 10.5%	10.0 to 13.0%	5.0 to 13.0%
Carbonate of lime and magnesia	78.0%	87.0%	72.0%	87.5%	63.0%
Penetration at 25° C (77° F) of impregnating bitumen	20 to 55	30 to 60	200 to 225	15 to 25	5 to 20

(1) Buckhorn, Okla.; (2) Brunswick, Okla.; (3) Ravia, Okla.; (4) Uvalde County, Tex.; (5) Clear Creek, Utah.

Bituminous Sandstones. In most of these deposits the material is very imperfectly impregnated and the rock does not break down after the extraction of the bitumen from it. In some of them the bitumen is too hard and requires fluxing; in others, it is too soft or present in too great quan-

tities and bituminous sandstones have been mixed with them with good results, notably in the case of the Buckhorn bituminous sandstones and limestones, mixtures of which have been laid in Kansas City, Mo. Some excellent pavements have been laid in Beaumont and San Antonio, Texas, by mixing the pulverized Uvalde County bituminous limestone with flux to soften the hard bitumen or with flux and sand.

Table IV.—American Bituminous Sandstones

	1	2	3	4	5	6	7
Bitumen	18.5%	10.8%	17.5%	6.5%	7.5%	11.5%	10.5%
Passing 200-mesh	5.5%	4.2%	6.5%	8.5%	11.5%	8.5%	15.5%
Passing 100-mesh	4.0%	5.0%	25.0%	27.0%	22.0%	35.0%	17.0%
Passing 80-mesh	27.0%	10.0%	35.0%	25.0%	24.0%	23.0%	14.0%
Passing 50-mesh	40.0%	30.0%	12.0%	25.0%	30.0%	20.0%	25.0%
Passing 40-mesh	3.0%	15.0%	3.0%	6.0%	4.0%	2.0%	10.0%
Passing 30-mesh	2.0%	12.0%	1.0%	1.0%	1.0%	....	5.0%
Passing 20-mesh	....	8.0%	....	1.0%	....	....	3.0%
Passing 10-mesh	....	5.0%	....	....	....	....	....
	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Penetration at 25° C (77° F) of impregnating bitumen	Very soft	Very soft	Very soft	Very soft	Very soft	Very soft	Very soft

(1) Carpinteria, Santa Barbara County, Cal.; (2) Santa Cruz, Cal.; (3) Santa Cruz, Cal.; (4) Breckenridge County, Ky.; (5) Green River, Warren County, Ky.; (6) Buckhorn, Okla.; (7) Whitmore Canon, Utah.

The Carpinteria sands are too rich in bitumen to make a satisfactory pavement altho they have been used to some extent in and around Santa Barbara. The Santa Cruz material if carefully selected makes a very satisfactory light traffic pavement and a large amount of it has been laid in San Francisco. Where failures resulted, it was chiefly due to lack of care in selecting the material. Certain of the Kentucky rock asphalts have been used in Louisville, some of the pavements being very poor, due to ignorance and poor selection of material, and others being very good. A number of excellent pavements were laid in the above City by mixing a certain proportion of the heated bituminous sandstone with an ordinary sheet-asphalt mixture. Where the rock has been uniformly impregnated with bitumen, the coating of the particles is usually much more thoro than is possible in an artificial mixture. This is especially true where the mineral aggregate is composed almost wholly of very fine particles, as in the case of certain of the European limestone rock deposits. The difficulty of obtaining uniform material in which the consistency of the bitumen and the grading of the mineral aggregate are satisfactory is, however, very great. In a sheet-asphalt pavement this is easily regulated. The sand which constitutes 70 to 80% of it is derived locally, and this is often true of the filler as well. While the freight rate on the asphalt used may be high, it only constitutes approximately 10% of the pavement. Where a natural bituminous rock is used, the entire pavement must be transported and when the distances are great this is a prohibitive handicap. For these reasons the rock asphalt industry of the United States has never assumed large proportions and most of the pavements have been laid in the immediate vicinity of the deposits. Some cities, notably Buffalo, have used a certain proportion of European rock in their sheet-asphalt paving mix-

tures with success. If finely ground, it takes the place of the filler and is already thoroly impregnated with bitumen.

26. Theory and Composition of Rock Asphalt Pavements

The Theory governing bituminous sandstone mixtures is substantially the same as for sheet-asphalt mixtures. In the case of bituminous limestone pavements made from European rock asphalts, the mineral aggregate is largely composed of 200, 100 and 80-mesh particles, which of themselves pack dry and possess great stability. These particles are impregnated with a very soft bitumen. Considering the surface area of the particles, the amount of the bitumen is relatively much smaller than that used in sheet-asphalt pavements. For the above reasons the wearing course of European limestone rock asphalt pavements is possessed of great stability and very rarely shoves under traffic. This is not true of the bituminous sandstone pavements, most of which, unless impregnated with a very hard bitumen, are lacking in stability.

Table V.—Composition of Rock Asphalt Pavements

	1	2	3	4	5	6
Bitumen	9.0%	8.5%	12.9%	13.4%	15.8%	9.7%
Passing 200-mesh	35.0%	16.5%	19.1%	14.6%	18.2%	12.3%
Passing 100-mesh	16.0%	8.0%	8.0%	4.0%	22.0%	22.0%
Passing 80-mesh	15.0%	19.0%	8.0%	5.0%	15.0%	24.0%
Passing 50-mesh	14.0%	14.0%	19.0%	13.0%	10.0%	28.0%
Passing 40-mesh	8.0%	9.0%	6.0%	7.0%	11.0%	2.0%
Passing 30-mesh	2.0%	12.0%	13.0%	9.0%	3.0%	1.0%
Passing 20-mesh	1.0%	8.0%	10.0%	9.0%	3.0%	1.0%
Passing 10-mesh	....	5.0%	4.0%	10.0%	2.0%	....
Retained 10-mesh	....	....	....	15.0%	....	....
	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

(1) Plaza, 5th Ave. and 59th St., New York City, European limestone rock asphalt; (2) Kansas City, Mo., mixture of Oklahoma bituminous sand and limestone; (3) San Antonio, Tex., Uvalde County, bituminous limestone fluxed; (4) Beaumont, Tex., bituminous limestone fluxed; (5) San Francisco, Santa Cruz bituminous sandstone; (6) Louisville, Ky., mixture of Kentucky bituminous sandstone filler and asphalt cement.

CONSTRUCTION AND MAINTENANCE

27. Methods of Manufacture and Laying

Manufacture. If the mineral aggregate is naturally in a fine state of division and only held together as a solid mass by the cementing power of the bitumen which it contains, it will usually be unnecessary to pulverize it; otherwise, it must be passed thru rollers and disintegrators and then screened to separate any lumps which may remain. The American and European limestones require crushing, while most of the bituminous sandstones do not. After crushing they are then heated in revolving drums somewhat similar to the sand dryers used in sheet-asphalt plants but having a much smaller grate area as great care must be taken not to overheat or burn the material. Usually a definite charge is placed in the drums and subjected to a heat of not over 177° C (350° F). The drum is con-

tinuously revolved until the powdered rock reaches a uniform temperature of approximately 149° C (300° F). This usually requires about 2 hr. Continuous feeding, as in a sand drier, is not often practiced, as, to insure sufficient heating during the passage of the material thru the drum, there would be too great danger of burning it. This heating is sometimes done in shallow iron pans with a slow fire underneath, the powdered rock being continually turned over by hand during the process. Where asphalt cement or sand is to be added, the ordinary type of asphalt mixer, sand drier, etc, must be provided in addition to the equipment above described. If no such addition is required, the bituminous rock is ready to lay on the street as soon as it comes from the heating drum.

Laying. The hot powder is transported to the street in wagons and spread with hot iron rakes to a uniform depth in much the same manner as a sheet-asphalt pavement. Bituminous sand mixtures are usually rolled and finished in the ordinary way. Bituminous limestone pavements are sometimes, but not always, rolled with a light hand roller as soon as they are raked. Immediately thereafter they are tamped over their entire surface with round tampers from 6 to 7 in in diameter, after which they may or may not be rolled with a 5 to 10-ton steam roller. Joints are made in the customary manner and smoothers are sometimes used on them, but the freshly cut edges are not painted with asphalt cement. In a bituminous limestone pavement the compression effected as above described results in the production of a skin of compressed paving mixture on the surface. The lower portion of the wearing course receives much less compression than does a sheet-asphalt pavement similarly treated, as the powdered rock is light and fluffy and can only be compacted thruout with great difficulty and years of traffic are required to produce ultimate compression. This does not militate against the successful use of this material as a pavement, however. In fact, shortly after ultimate compression has been reached, the pavement commences to disintegrate. The street tools used differ but little from those employed in the sheet-asphalt paving industry.

28. Specifications for Construction

These vary greatly with the kind of material used and the method of manufacturing or tempering it. Owing to the limited use of rock asphalt pavements in the United States, these specifications are not as detailed or as nearly standardized as are sheet-asphalt paving specifications.

Borough of Manhattan, New York City, 1912 Specifications. "Should any of the rock asphalts be used, the material shall be a natural bituminous limestone or sandstone, or a mixture of the two, and shall be prepared and laid in the following manner:

"The lumps of rock, after being mixed in the proper proportions, shall be finely crushed and pulverized, and the powder passed thru a 20-mesh sieve. In case of the use of any asphaltic limestone, or a mixture of an asphaltic limestone and an asphaltic sandstone, nothing whatever shall be added to or taken from the powder obtained by grinding the natural bituminous rock. Should it be proposed to use an asphaltic sandstone only, which contains more than 9% of natural bitumen, of such a consistency that the resulting pavement would prove too soft to sustain traffic, the material, if satisfactory in other respects, shall be made to conform with the requirements of these specifications by the addition of inorganic dust, in such manner and in such proportion as the Engineer may direct. The powder shall contain from 9 to 12% of natural bitumen.

"This powder shall be heated in a suitable apparatus to 93° to 121° C (200 to 250° F), and must be brought to the ground at a temperature of not less than 82° C (180° F) in carts made for the purpose, and carefully spread as specified for refined asphalt pavement, to such a depth that, after having received its ultimate compression, it

will have a thickness of 2½ in when laid on concrete. When the foundation is other than concrete it shall be laid on a 1-in binder course as heretofore prescribed, and the net thickness of the rock asphalt wearing surface after compression shall be 2 in. The surface shall be rendered perfectly even by tamping, smoothing, and rolling with heated appliances of approved design."

Specifications Proposed in 1911 by the Assn. for Standardizing Paving Specifications. "The bituminous rock or rock asphalt for use in the wearing surface must be ground to such a fineness that its mineral aggregate, after being freed from the bitumen by the use of carbon disulphide, shall all pass a 4-mesh sieve. The wearing surface made of the bituminous rock or rock asphalt must contain between 9.5 and 12.5% of bitumen soluble in carbon disulphide. The ground rock asphalt shall be heated separately to not over 177° C (350° F) or below 121° C (250° F). These heated materials shall then be combined and thoroly mixed in an asphalt mixer in the required proportions to produce a wearing surface complying with the above specifications. The mixture prepared in the manner above described shall be brought to the streets in carts at a temperature between 107° and 163° C (225° and 325° F) and shall be laid as specified in the specifications for sheet-asphalt paving."

29. Construction Cost Data

These vary so much with the price of the raw material and the manner in which it is manipulated that it is impossible to give any typical statement. Street labor is about the same as in sheet-asphalt. Plant labor is usually somewhat less. Superintendence, etc, is about the same. Cost of plant, interest charges and depreciation depend upon the kind of material used and the method of manufacturing it. Given the price of the raw material at any given point, the cost of the pavement may be calculated in the same manner as given under sheet-asphalt.

30. Methods of Maintenance

In European limestone rock pavements defective material is cut out down to the foundation and replaced with new material and the surface heater method of repairing is not used. This practice is usually followed in bituminous sandstone pavements but there would appear to be no reason why in certain instances a surface heater could not be successfully employed.

Guarantee Periods. In the United States these are usually the same as for sheet-asphalt pavements; that is, 5 years, altho some of the European cities call for a 2 years' free maintenance period and pay a definite sum per annum for maintenance during the succeeding 15 years.

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SECTION 18

WOOD BLOCK PAVEMENTS

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GENERAL DATA

1. Historical Development

Russia. The first wood block pavements are said to have been laid in Russia several hundred years ago. The blocks were hexagonal in form and laid with a certain amount of care, but, as they were not used to any great extent or for any length of time, very little information is obtainable about them. In Petrograd, in 1912 there were in the city 689 000 sq yd of wood pavement, which is 6% of the entire pavement area.

In London the first wood pavement was laid in 1839; this consisted of hexagonal blocks of fir, some 6 to 8 in wide and 4 to 6 in deep. The blocks were laid on a foundation of gravel that had previously been rolled. They were bevelled or grooved on the edges so as to afford a foothold for the horses. The first pavements were not successful, but others soon followed, and the Engineer of the Sewer Commission stated, in a report made in 1874, that, counting the size of the blocks as constituting a difference, there must have been more than two dozen different kinds of wood pavements experimented with in the city previous to that time.

A system, known as CAREY'S consisted of blocks 6½ to 7½ in wide, 13 to 15 in long, and 8 or 9 in deep, the sides and ends having projecting and reëntering angles, locking the blocks together to prevent unequal settlement. Pavements of this kind were laid in 1841 or 1842. They required renewing, however, every 3 or 4 years. The dimensions of these blocks

were afterwards modified, and finally reduced to a width of 4 in and a depth of 5 or 6 in, the reëntering angles also being discarded.

The IMPROVED WOOD system was first adopted in 1871. On a subgrade, a bed of 4 in of sand was laid, and upon that two layers of 1-in deal boards, saturated with boiling tar, one layer across the other, were laid. The blocks were 3 in wide, 5 in deep and 9 in long. They were also dipped in tar and laid on the boards with the end joints closed, but the transverse joints were ¾ in wide, the space being maintained by pieces of boards nailed to the foundation and also to the boards. The joints were filled with rammed gravel, then a composition of pitch and tar was poured in until the joints were completely filled, when the surface was also covered with tar, gravel, and sharp sand. The foundation was somewhat elastic and maintained the even surface of the pavement as long as it was in shape, but when the pavement became pervious to water it settled and became rough and uneven. This was probably the first use of the tar and gravel joint for pavements of any description.

In 1872 a cement-concrete foundation was first used for a wood pavement. The concrete was 4 in thick and was laid by the Ligno Mineral Co. The blocks were of beech, mineralized by a special process, 3½ in wide, 4½ in deep, and 7½ in long, with the ends cut to an angle of 60°. They were laid with the ends inclining in opposite directions in alternate courses. In a few years, however, this form of block was abandoned for the rectangular, and fir was used instead of beech. The blocks were bedded in Portland cement and laid with joints ¼ in wide, partly filled with asphalt, and then grouted with mortar. It was thought after a few years' experience that the laying of the blocks directly upon concrete made so rigid a construction that the blocks wore more rapidly under traffic than they otherwise would. There were several means devised for overcoming this and making the pavement more elastic. The Asphalt Wood Paving Co. laid ½ in of asphalt upon concrete, and formed also the lower part of the joint with the same material, and the upper part with a grout of Portland cement and gravel. In addition to the elasticity, it was claimed that this also gave a perfectly watertight joint. One objection to this method, however, was that the asphalt softened under blocks when the weather became hot, allowing them to settle unevenly under traffic, making the pavement generally uneven and consequently causing abnormal wear.

In HENSON'S method the blocks were laid close, with a strip of roofing felt from 1/16 to 1/8 in thick, cut to the same width as the depth of the blocks, laid between each course. The joints were thus closed as completely as possible, leaving only the actual fabric of the felt, the material support of the blocks saving them from the rapidly destroying action of spreading at the edges. The protection of the wood was further enhanced by a layer of similar felt over the whole surface of the concrete foundation upon which the wooden blocks were cushioned. Another object of laying the felt between the blocks was to take up any longitudinal expansion that might occur on account of the changes of the atmosphere. It was thought that the felt would be thick enough to provide for the expansion of any one course of blocks. The results justified this method, which was somewhat expensive, but the endurance of the blocks was said to be increased from one-half to two-thirds by this freedom from the joining of the blocks and the mutual support of the edges. In order to provide for the transverse expansion a space of 1 or 1½ in was left along the curb and filled with asphalt and sand or gravel. In some cases, however, the row of blocks

next to the curb was left open until the greatest amount of expansion had taken place, and then filled in. The kind of wood used in London at that time was generally Swedish deal, and the blocks were generally laid without any chemical treatment, since that was considered of doubtful advantage, and as they wore out under traffic rather than failed from decay. It was not thought that creosoting or similar treatment would benefit the wearing qualities.

In 1874 Haywood made an extensive report to the Commissioners of sewers of London upon the comparative merits of wood and rock asphalt pavements. At that time there were but 12 238 sq yd of wood pavement and 30 802 sq yd of rock asphalt, quite a portion of the area previously laid with wood having been replaced with rock asphalt. In a table which he presented at that time he gave the actual life of wooden pavements that had been laid at different times since 1841 as varying from 5 years and 5 months to 19 years and 1 month. The pavement having the longest life, strangely enough, was the first one laid of those in the table. The average cost per square yard during life, including repairs, varied from 1s. 5¼d. to 3s. 4d. (35 to 81 cents), which last pavement had a life of 12 years and 3 months. He gave the average life of the pavements in the three streets of the largest traffic as 9 years, and those of the least traffic as 11 years and 3 months. His conclusions on the whole were more favorable to rock asphalt than to wood, altho the experience with rock asphalt at that time extended over a period of only 5 years, but later experience has justified his conclusions. London and Paris at the present time are using wood as a paving material, because it is less noisy than stone and less slippery than rock asphalt. On London Bridge, King William St., blocks wore 2⅝ in in 3 years and 2 months. Haywood estimated in general that the wear of wooden pavements would be from 0.2 to 0.3 in per year, under traffic of from 300 to 600 vehicles per yd for 12 hr.

In 1884 the wood pavements in London consisted generally of blocks 3 in wide by 6 in deep by 9 in long, altho the dimensions of length and depth varied somewhat.

Paris. Wood pavements were not used in Paris until 1881, but increased very rapidly, so that in 1911 Paris had 2 300 000 sq yd of wood pavement, which represented 21% of the entire pavement of the city. In Paris the blocks are laid on the heavy traffic streets, that is, streets where the bus and cab traffic is excessive. The material used at the present time is principally pine from the Landes and Swedish deal.

Germany. The total amount of wood pavement in Germany was reported in 1913 to be 1 085 968 sq yd, or 0.62% of the total amount of pavements in the different cities. About five-ninths of this pavement was laid with soft and four-ninths with hard woods, on a concrete base from 7 to 8 in thick. The blocks were 5.1 in deep, and, when impregnated by dipping, the pavement cost $4.06 per sq yd, with a 5-year guarantee, and $4.875 when the blocks were creosoted, with a 10-year guarantee.

Berlin has about 9 miles of wood pavement out of a total of 464½ miles. This city is practically level, the central business portion of it being paved almost entirely with rock asphalt. The River Spree runs thru the city, and there are many bridges over it. Wood pavement is used almost entirely on the approaches to these bridges, and also on the bridges over the railroad tracks. This is because the European rock asphalt is more slippery than the European wood, the reverse of what is found in this

country. The average life of the soft wood pavement in Berlin is taken as 12 years, and the cost of repairs about 17 cents per sq yd.

Quebec. Tamarack pavements have been laid in Quebec since 1855. The blocks are laid on a wooden flooring of 1½-in boards, laid longitudinally and crossed at right angles by a second flooring of 1-in boards so as to conform more readily to the crown of the pavement. Upon this flooring blocks about 12 in long, sawn from logs 10 to 15 in in diameter, are laid on end. In the spaces between the blocks small pieces of wood are forced, and the remaining interspaces filled with a grout made of sand, cement and tar, or sometimes a mixture of finely sifted coal ashes and cement. These roadways are very durable, it being stated that pavements, after having been in use 35 years, were taken up, when the blocks showed no signs whatever of any decay, but had been worn to one-half their original depth. These pavements cost from $1.55 to $1.75 per sq yd.

Boston, New York City and Philadelphia. In the United States the first wood pavements were laid about 1839, in Boston, New York and Philadelphia. No special care was paid to the character of the wood of which the blocks were made or to the method of laying, and they received no treatment whatever. It is not surprising, therefore, that the blocks soon decayed, and the pavement got into such disrepair that it had to be relaid.

A Committee of the Franklin Institute of Philadelphia in 1843 stated in a report that "The hexagonal hemlock pavement laid some years ago in Chestnut St., between Fourth and Fifth, cost $2.50 per sq yd, and was decayed to such an extent as to require renewal within 3 years. The squared-block wood pavement in Third St., of Northern spruce, cost about $2.25 per sq yd, and after 3½ years' use the hemlock portion of it was very much decayed and needs renewal, while the heart yellow-pine portion is still in apparently good order, although presenting strong symptoms of decay. This pavement was laid in Sept., 1839. Finally, in consequence of the slippery nature of their surface, their deficiency of durability when of ordinary timber, of their expense in the ultimate, and in view of results of experience as far as they have become known to us, we are reluctantly impelled to the conclusion that, tho their use may be proper in some detached situations, wooden pavements ought not at this time to be recommended as part of the general system of paving by the city of Philadelphia." The Committee also stated that the authorities of New York had determined to take up the wood pavements and relay them with stone, and that the experience of Boston had been practically the same as that of Philadelphia and New York City.

Washington, D. C., is a city in which experimental pavements of many kinds are laid. The Board of Public Works was appointed in 1871, and at that time 100 000 sq yd of wood pavement had been laid in Washington and Georgetown. The exact type is not known, but probably quite a large proportion of it was the Nicholson, as that had been laid in many cities previous to that time. Subsequent to 1871, and under the authority of the Board of Public Works, there were laid in Washington over 1 000 000 sq yd of wood pavements, under twelve separate patents; they cost from $2.00 to $4.20 per sq yd. They soon began to decay and to be replaced, so that between 1875 and 1878 over 315 000 sq yd had been removed. From this time they were replaced gradually by other material until 1887, when 18 403 sq yd only were left, and these were removed in 1889.

In a report to the Engineering Department in 1887 the Commissioner says: "Cedar block pavements used so extensively thruout the Northwest are cheap, $1.00 to $1.30 per sq yd, but deteriorate rapidly, are objectionable on sanitary grounds, and are anything but smooth for street wear. Creosoted wooden blocks, with a hydraulic cement foundation, when closely laid, approach nearest to the ideal block pavement. Those in the form of the blocks of the Ker Pavement Co., New York City, are a fair

example of this class. These are laid with creosoted wood blocks, 6 by 9 by 8 in in dimension. The wood fiber is placed vertically to a depth of 6 in; ⅝-in joints are left which are filled, 1 in with hot asphalt and 3 in with Portland cement grouting. The resulting pavement is clean, noiseless, smooth, and not slippery." Altho this pavement received so great an endorsement, it was not used to any extent.

Nicholson Wood Block Pavement. Wood pavements, however, came into use very generally in the United States between 1860 and 1870, laid under the Nicholson patent. Probably the best idea of this pavement can be obtained by quoting from the Brooklyn, N. Y., specifications in a contract made in 1869:

"The wooden blocks of the Nicholson pavement are to be of sound white pine or southern yellow pine, sawed so as to be 3 in thick and 6 in long; the blocks for paving the kennel to be sawed to a uniform level so that a channel-way for surface water will be formed outside the curb-lines. The flooring for blocks, and the pickets to be used between each transverse course of blocks, to be of sound common pine boards, conforming to 1 in thickness, the whole 2 in wide and 1 in thick. The foundation or sand bed which is prepared is to be brought to a proper crown and width to the street edge and then covered with sound common pine boards of the dimension described, paved lengthwise to the line of the street, the ends resting on similar boards laid transversely from curb to curb; the flooring to be well and thoroly tarred on both sides with hot coal tar brought to the proper consistency with paving cement, so as to be tough and fibrous and not brittle when cool. Upon this floor of plank the blocks are to be set on end in parallel courses, transversely with the line of the street; each block before laying to be dipped to half its height in hot coal tar and paving cement prepared as described; each course to be separated by a course of pickets placed on the face of the blocks and to be properly nailed; the space between each course of blocks about the pickets to be filled with clean roofing gravel and hot coal tar, and then the cement thoroly mixed and compactly rammed by means of a paver's rammer and an iron blade made to fit the interstices or spaces between the blocks; the gravel to be very thoroly dry and warm, so as not to chill the tar; the coal tar in all cases is to be boiled down and so thickened with paving cement as to be tough and fibrous when cool and not brittle even in cool weather, and is to be applied hot and in such quantity as will thoroly penetrate and fill all the joints; the whole surface of the pavement, as rapidly as the grouting shall be completed, is to be covered with hot tar and paving cement as above specified, and then covered with fine sand and gravel and not less than ¾ in thick."

The Nicholson pavement in Brooklyn, N. Y., cost $4.50 per sq yd, with an additional sum of 50 cents per sq yd for grading the street and preparing the foundation. The blocks for this pavement could be either treated chemically or not, according to the belief of the special set of authorities in control, but as a matter of fact they were laid without treatment. This pavement, when first laid, was very smooth and presented a pleasing appearance to the eye, and for a time was extremely popular. It soon began to decay, however, and was rough and uneven unless frequently repaired, and, as the decay continued, became unhealthy and unsanitary. Its average life in Brooklyn, N. Y., was about 6 years; in St. Louis 5 years and 6 months. Memphis, Tenn., laid a large amount of this pavement, but it soon decayed, requiring relaying with entirely different materials.

Alexander, Miller & Co.'s Improved Wood Pavement, which was very similar to the Nicholson, was laid at about the same time. The principal difference between this and the Nicholson was in the shape of the blocks, which were sawed on a bevel so as to be 4 in thick at the base, 3 in thick at the top and 6 in deep, so that when set together at the bottom they left an open joint 1 in wide at the top. In Brooklyn these blocks were laid on burnettized spruce planks 1½ in thick. These planks were laid lengthwise of the street, resting on similar planks laid transversely from curb to curb. The spaces between the blocks were filled with coal tar

and pitch, and the surface of the pavement was covered in the same way as that prescribed for the Nicholson pavement. This pavement cost in Brooklyn $4.90 per sq yd, and its life was practically the same as that of the Nicholson.

Round Cedar Block Pavements. Between 1880 and 1890 all Western cities had a rapid growth, and consequently there was a great demand for street pavements. These cities, being far from the supplies of stone, naturally took kindly to the representations of the agents for wood pavements, as the pavements were cheap, and it was hoped that the property on the abutting streets would be sold before the pavements required relaying. These pavements were ordinarily known as cedar block pavements. This material came from the North, and was especially cheap in Chicago and Detroit, where water transportation could be had, but it was also laid in Omaha, Neb., and in the larger cities of Iowa. The blocks were made from cedar posts, from which all the bark had first been removed, and sawed into pieces 6 in long, by gang-saws cutting from six to eight blocks at once. These blocks varied in diameter according to the dimensions of the posts, but the specifications generally called for them to be from 4 to 8 in in diameter, or, if larger, the blocks were split before being laid in the pavement. They were laid on different foundations such as sand, sand and gravel, sand and broken stone, sand and hemlock boards, and concrete with a sand cushion. The great and almost only merit of these pavements was their cheapness. They were quickly laid, and, when new, made a pleasing and apparently satisfactory roadway. The blocks were laid on the foundation very simply, the only object being to get them close together so as to form as small a space as possible between the individual pieces. The blocks were rammed and the space filled with clean, coarse gravel previously heated and dried, and then poured full of paving cement composed of coal tar pitch, the specifications generally requiring 2 gal per sq yd. Between 1880 and 1890 many millions of yards of this pavement were laid in the cities of Chicago, Detroit, St. Paul, and Minneapolis, Minn., Omaha, Neb., Kansas City, Mo., and many other smaller cities thruout the Central West. The pavement being cheap and all of these cities at that time having an unprecedented growth, a much greater amount was laid than would have been laid under ordinary circumstances, as the real estate boomer desired to have a paved street in front of his property long enough to sell it, no matter what might be its eventual life. This pavement lasted ordinarily about 5 years in good condition, when the decay was generally so great as to make it rough and undesirable for travel, and in a few years more it became practically impassable and required renewal when it had been down 7 years.

Chicago probably had more cedar block pavement than any other city. On Jan. 1, 1897, there were 752.68 miles of this pavement, and during the year there were laid 23.53 miles. On January 1, 1900, the mileage was 763.21. In 1897 the average cost of this pavement laid on a plank base was 70 cents per sq yd, and when laid on 6 in of broken stone, 85 cents per sq yd. The City Engineer said at that time: "The plank foundation is considered to be the best, as the wearing surface is more even, and the planks last as long as the blocks, and whenever the pavement is renewed the street is torn up, as, for instance, by the gas company renewing the calking of their pipes, and the city laying new conduits. In such cases it is necessary to relay the macadam." On Jan. 1, 1911, the cedar block pavement in Chicago had been reduced to 273.59 miles, and on Jan. 1, 1915, to 214.55 miles.

Detroit also laid a considerable quantity of this pavement. Both this city and Chicago, however, recognized that it was a temporary pavement only, but with its low cost it was considered to be, under the circumstances, an advisable proposition. A small amount of this material was laid in Detroit in 1914; the blocks, however, were only 4 in deep and laid on concrete, so that when they did decay the base would remain in good condition and at proper grade, and it could be economically refaced with a new pavement. The following are the specifications for the 1914 pavement:

"**Cushion.** To secure a smooth surface to the pavement there shall be spread by means of a template, shaped to conform to the true cross-section of the street, when compacted and rolled with a roller weighing not less than 200 or more than 300 lb, 1 in of clean bank, lake or river sand free from all loam or foreign matter. The sand must pass a ¼-in screen. On streets having car tracks a mortar cushion shall be used, composed of one part Portland cement and four parts fine river sand, said cushion to extend 2 ft outside of track.

"**Cedar Blocks.** Cedar blocks shall be 4 in long, of the best quality of sound, selected, live timber, stripped of all bark and free from all traces of rot or indications of decay, and shall not measure less than 4½ in nor more than 9 in in diameter, and shall be so selected in size as to make as close-jointed a pavement as possible. The contractor must furnish all labor to cull the blocks under the supervision of the Commissioner of Public Works or his representative. All condemned blocks shall at once be removed from the street.

"**Filling.** The spaces between the blocks shall be filled with screened gravel or crushed granite or boulders of size varying from ½ to 1 in in diameter and free from dust, sand, loam or thin stone, screened when necessary, thru a wire screen, to set at an angle of 60°, with meshes not less than 8 in lengthwise by ½ in in width; tamped with iron tamping bars and refilled and retamped as often as required by the Commissioner of Public Works or his representative, and then the surface shall be well rolled by the city roller at a cost to the contractor of ½ cent per sq yd. After rolling, the spaces between the gravel or stone filling of the blocks shall be completely filled from the bottom to the top with paving cement obtained from the direct distillation of coal tar, and shall be the residuum thereof, such as is ordinarily numbered 5 or 6 at the manufactory, or any other approved composition. The quality of the composition, and the temperature at which it shall be heated, shall be satisfactory to the Commissioner of Public Works. Extra material and care shall be used at the gutters in filling all joints, in paving around catch-basins, or other receptacles, to effectually prevent the leakage of any water into the sub-roadway; all joints to be completely filled to the top before adding top dressing. No teaming shall be permitted over the pavement until the spaces are filled as above specified."

In 1888 many of these cities laid pavements practically the same as those just described, except that the material was cypress from the swamps of Arkansas. This wood was much heavier than cedar, more dense and compact, and, from its appearance, should be more durable, but there is probably no material produced by nature about which as little can be ascertained by a preliminary examination as wood. The only sure way to find out its durability is by experience. In an actual test for abrasion, cypress would probably have outlasted cedar, but as far as decay from the atmosphere was concerned it was much shorter-lived, and the cypress blocks had not been laid more than 2 years before they began to show serious signs of decay. This in itself proved beneficial, as it prevented a larger amount from being laid. While heart cypress has deservedly a good reputation for durability, the sapling wood in all of these instances plainly showed itself of no value. One street in Omaha which was paved with cypress blocks in 1888 was repaved with brick in 1892, and the other streets paved with the same material had about the same life. When the Tenth St. viaduct in Omaha was completed in 1889, it was decided to pave the roadway with cypress blocks; but in this instance the inspector went to

the Louisiana swamps to see the timber cut and sawed, selecting only the best trees, so that the best results could be obtained. Despite this precaution the pavement lasted but 9 years.

In San Antonio, Texas, a certain amount of mesquite blocks, hexagonal in form, were laid at quite an early date and as late as 1914. In 1889 the City Engineer of Galveston, Texas, where pavements of this material had been laid, wrote as follows:

"We have some creosoted pine blocks from 6 to 10 by 4 by 6 in. About 75 000 sq yd were laid in 1874, which, even now, except where the pavement has been disturbed for street-car tracks, gas and water pipes, is in good condition. The blocks were laid at right angles to the sidewalk curbs on a sand foundation, with a 1-in space between, which space was filled in with a wedge driven down about 2 in below the top surface of the blocks and penetrating about 2 in into the foundation below the bottom of the block, the space above the wedge being filled with tar and gravel, and in 1892 to 1895 inc. there were laid some 4 or 5 miles of creosoted pine block pavement. In this instance the blocks were laid touching without any wedges, and tar was spread over the top, and sand over the tar. This last pavement has given endless trouble by swelling and buckling, and kicking out the sidewalk curbs after every rain, especially when the rain followed a dry spell. I relaid a couple of blocks, about 3500 sq yd, with wedges and tar and gravel with some of the displaced blocks about a year ago, but it is beginning to show distress. We have some cypress blocks, laid with wedges some 10 or 15 years ago, that did good service for 8 or 10 years, but they are now rotten and in a very unsanitary condition. If enough oil is put in pine blocks to prevent swelling, I am satisfied that they would make excellent paving material. They have a wonderful ability to resist abrasion."

Preservative Treatment. Experience demonstrated plainly that if wood was to be used as a paving material in the United States, it would require chemical treatment. Indianapolis, Ind., was the first city in the country to lay pavements in this manner. The first wood pavements laid there, however, were of red cedar rectangular blocks from the State of Washington, without any treatment. The blocks were laid with close joints, on a concrete base, with a 1-in sand cushion, but they soon showed wear and in a short time began to decay. In 1896 four streets were paved with the same material, except that the blocks were creosoted. The blocks were 4 in wide and 5 in deep, laid at an angle of 45° with the curb. The joints were laid close, and no provision was made for expansion at the curb. Some trouble was experienced on account of the blocks bulging, mainly with the untreated blocks, but some with the creosoted blocks, so that the Board of Public Works adopted long-leaf yellow pine for the material and treated the blocks with creosote oil. The blocks were laid as before described, except that a space 1 to 2 in wide was left along the curb for expansion; this space was filled with sand and covered with paving pitch. The interstices between the blocks were partially filled with fine, dry sand, when the entire surface was rolled smooth, and then covered with hot paving pitch and fine gravel screenings. These pavements cost from $2.10 to $2.50 per sq yd. But little was known at that time of the treatment of blocks or of the character of the oil.

The specifications in Indianapolis in that respect read as follows: "After the blocks have been inspected and found satisfactory, they shall be placed in an air-tight chamber, where, by means of superheated steam and the use of a vacuum pump, all sap in the blocks shall be vaporized and then removed. When the blocks are thoroly dry, and while the cylinder is under a vacuum of 15 or 20 in, heavy creosote oil, weighing 8.8 lb per gal, shall be admitted into the cylinder and pressure added until the pressure in the cylinder shall be at least 50 lb per sq in. The blocks shall remain in the cylinder until they have absorbed 10 lb of oil per cu ft of timber and until the creosote has impregnated the timber uniformly thru the entire thickness of the blocks." The

joints were filled with paving cement composed of 10% of refined Trinidad asphalt mixed with 90% of coal tar paving cement distilled at a temperature of not less than 315° C (600° F). The surface of the pavement when completed was covered with ½ in top dressing of clean, coarse sand or granite screenings.

Creosote Oil and Rosin. The success of these Indianapolis pavements was such that promoters were desirous of extending them to the East, and a method of treatment was originated which provided that the blocks should be treated with a preservative composed of 50% of creosote oil and 50% of rosin. The idea of the rosin was that, as creosote is a very volatile substance, it was necessary to provide some means of keeping it in the blocks, and it was thought that by mixing it with the rosin that result would be brought about, and experience seemed to demonstrate that such was the case.

In 1900 the first pavement of this character was laid on Tremont St., in Boston, in front of the Common. The blocks were 4 in deep and 4 in wide, laid on a concrete base. When these blocks had been in use 14 years the pavement was in good condition and showed very little wear, and it had cost a very small amount for repairs.

In 1902, Brooklyn, N. Y., laid a pavement of this type as an experiment. It was so pleasing, however, and bid fair to be so satisfactory, that the following year specifications were drawn up and a considerable amount of wood pavement laid. In order to obtain competition, the specifications provided that the wood should be treated with a preservative composed of 50% of creosote oil and 50% of rosin or some other suitable waterproofing material. It was also specified that the blocks when treated should sink in water, and when dried for a period of 24 hr at a temperature of 38° C (100° F) they should not absorb more than 3% of water upon being immersed for 24 hr.

Coal-Gas Tar Oil and Water-Gas Tar Oil. On account of the increase in the cost of rosin, in the Borough of Manhattan, New York City, the specifications were changed to permit the preservative to be composed of 75% of creosote oil and 25% of rosin; and in 1909 a committee was appointed by the Board of Estimate and Apportionment of the City of New York, composed of the Chief Engineer of the Board, the Chief Engineer of the Department of Finance, and the Chief Engineers of the Bureaus of Highways of the different boroughs to draw up specifications for wood blocks. After many hearings, at which were present many manufacturers of blocks, the following specification was adopted and sent to the Board of Estimate and Apportionment, which approved it.

"The oil with which the blocks are to be treated shall be a stable, antiseptic and waterproofing oil from which the water has been removed by distillation, and which shall have a specific gravity of not less than 1.12 at 38° C (100° F). When distilled in the manner hereinafter described, the oil shall lose not more than 35% up to a temperature of 315° C (600° F). The distillate between 255° and 315° C (491° and 600° F) shall have a specific gravity not less than 1.02, the said specific gravity being taken at a temperature of 15.5° C (60° F)." It will be noticed that the requirement is made that the distillate between 255° and 315° C (491° and 600° F) shall have a specific gravity of at least 1.02. The reason for this was because certain manufacturers claimed that water-gas tar oil should be allowed as well as coal-gas tar oil. The committee was hardly willing to accept this, as it deemed that there had not been experience enough to demonstrate the merits of the water-gas tar oil, but felt that it could allow a mixture of the two if the amount of water-gas tar oil did not exceed 50% of the mixture, and with the specific gravity requirement of 1.02 for the distillate it was thought that an excess of the water-gas tar oil would be avoided. This was found to work out satisfactorily in practice.

Development in United States. Treated wood block pavement has rapidly come into use, so that on Jan. 1, 1914, there were 9 670 000 sq yd in the United States. Naturally there have been many differences of opinion as regards the specifications under which it should be laid, not only as to the character of the wood, but also as to the character of the preservative, and the amount to be used.

2. Characteristics

The 3rd Int. Road Congress held in London in 1913 adopted the following conclusions relative to wood block pavement:

" 1. Where gradients permit, wood block pavement is very suitable for streets where traffic is great, but is not of the exceptionally heavy character usually existing on streets near docks or similar centers of industrial traffic. It should be used where a noiseless pavement is desirable. It is of great importance that a concrete foundation should be laid of sufficient strength to carry the traffic passing over the pavement.

" 2. Great care is necessary in the selection of the proper timber for the purpose, and all soft wood blocks should be thoroly impregnated with a well-proved preservative before being laid.

" 3. In view of the varying results given by wood pavements, according to local circumstances, it is desirable that further investigations and laboratory experiments should be carried out in connection with the selection of the timber and of the impregnating preservative.

" 4. Every precaution should be taken in laying the blocks to prevent, so far as possible, the entry of water thru the joints. Hard woods give varying results according to local circumstances, and it does not appear desirable to recommend them for roads with intense traffic in large cities, unless some means are devised to effectively prevent the rapid destruction of the joints and the resulting destructive effect on the concrete below. If these woods are employed it is desirable not only to prevent the percolation of water thru the joints to the foundation, but also to consolidate the blocks as far as possible so that they may not become rounded at the edges. Soft woods obtained from suitable kinds of trees, and especially from resinous species, are equally suitable for roads with a comparatively heavy and intense traffic as well as for roads with a light and infrequent traffic. In the latter, however, the blocks are liable to rot if they have not been suitably pickled. It is also desirable to make the joints as small and watertight as possible. On the other hand, their comparatively rapid wear on roads with great traffic should encourage one to make exhaustive investigations into the best means of treating them, so as to increase their strength without prejudice to their elasticity.

" 5. Subject to certain precautions, such as impregnating of the wood, waterproofing of the joints and surface, frequent cleaning of the roadway, etc, there is no objection to wood pavement from the sanitary point of view.

" 6. The spreading of gritting is necessary under certain conditions and in certain weather, especially on hard wood paving, to prevent the surface becoming slippery, but the gritting should be done with suitable small gravel, chippings, or sharp sand, so as to avoid, as far as possible, any injury to rubber tires."

3. Crowns

A general discussion of the crown of a pavement is covered in Sect. 19. The principles elucidated there apply to wood block pavements with as

much force as to stone; in fact, even to a greater degree. This is because, with wood block, being more slippery than stone, it is important to have the side slope as slight as possible, so as to prevent the slipping of horses sidewise. It is also important because, however well blocks are treated, there must be a certain amount of swelling, and therefore compression, in the individual blocks. The pressure thus exerted has a tendency to lift the blocks from the concrete, and the greater the crown of the street the greater will be the tendency of the pavement to rise as a whole. For this reason, therefore, if for no other, it is desirable to have the crown of a wood block pavement as light as possible, and at the same time allow the water to run freely to the gutters.

MATERIALS

4. Physical Properties of Wood Blocks

The Essential Qualities of wood for a good paving block are somewhat similar to those required for stone, that is, the blocks should be hard and durable, and should not wear unevenly or be slippery under traffic. If the blocks are too soft, the wood is liable to wear rapidly, or the fibers crush, so that it becomes rough and uneven; if the blocks are too hard, the surface is slippery, and that is one of the main objections to wood pavement.

The Selection of the Kind of Wood to be used is especially important, not only because wood as a whole is becoming more expensive year by year, but if a wood can be found that is suitable and one that is generally scattered over the country, it will materially reduce the cost of the pavement by lessening the cost of transportation. Then, too, more competition can be had if a large variety of material can be used.

Long-Leaf Yellow Pine. It has generally been considered that long-leaf yellow pine, which is extensively used, makes the best paving blocks of any wood that has been used. This material is brought to the North only at considerable expense. It is a wood that is in great demand for other purposes, so that the extra call upon it for wood pavements tends to increase its price. It is extremely hard, and stands heavy traffic remarkably well, the greatest objection to it being its slipperiness under traffic and its liability to split. The former objection can be overcome by sprinkling with sand on special occasions, and the latter by making the blocks deeper; this of course adds somewhat to the expense. The structure of this wood varies greatly, and to secure a fairly uniform quality it is customary to specify the number of rings per inch. The strength of wood varies according to its dry weight: the heavier the wood, the stronger it is. The weight depends on the thickness and number of wood cells. It is found that the cells in the summer or dark rings are smaller and have heavier walls than the spring wood. A rule for quickly determining the quality of long-leaf pine has recently been published by the U. S. Forest Products Laboratory. It states that pine in which the cross-section of the summer rings shows an area of 33% or over of the total corresponding annual ring is stronger than pine where the percentage of summer wood is less. This rule automatically rules out wide grained material that is undesirable and permits such wide grained lumber as should be used.

Tamarack is a wood that has been very successful wherever used. It is found in limited areas and in limited amounts, so that it cannot be considered as available for many localities.

Black Gum has been used, but not as successfully as pine. It requires

a greater amount of treatment, but, as it is softer than the pine, it is not quite as slippery. In 1907 and 1908 it was used to a certain extent, as at that time yellow pine was extremely expensive, but in recent years it has generally been discontinued as a paving material.

European Hard and Soft Woods. In Europe the wood used as a whole is divided into two classes, namely, hard woods and soft woods, the soft woods being generally pine or some kind of fir, and the hard woods Australian Jarrah or Karri. The Australian woods are as a rule untreated. They are extremely hard and wear well, except that they break at the edges, becoming rough under heavy traffic. They are so dense that they do not take treatment well, and so decay irregularly, and become rough for that reason also. A pavement of this Australian wood was laid in New York City in 1895; it was expensive and gave no better satisfaction than American woods.

Tests for Wood Blocks. Wood has never received in this country any special tests for the determination of its characteristics for paving purposes, but in Paris it is tested in the laboratory for imbibition, thrust, resistance to compression, wear by attrition, and resistance to blows. The blocks are also tested in a rot pit, so called, to determine the efficiency of the various methods of preserving the wood. The rot pit consists of a pit filled with manure into which the blocks, both treated and untreated, are buried from 18 months to 2 years, when they are taken out and examined. No other place is known where such tests are made.

Service Test Pavements. In 1906 an experimental pavement made up of different varieties of wood was laid by the Forest Service of the U. S. Dept. of Agr. in Minneapolis, Minn. For a complete description of the pavements and the results after 6 years' service, see the report by the Forest Service (44).

Description. The woods used in the improvement were long-leaf pine, Norway pine, tamarack, Douglas fir, western larch, white birch and hemlock. The long-leaf pine was included so as to provide a standard for comparison with the other varieties. The blocks were treated with 16 lb per cu ft of coal tar oil having a specific gravity of 1.09 at 20° C (68° F), except that the oil used in the white birch and western larch blocks had a lower specific gravity, so that 20 lb per cu ft was used in the case of these species to compensate as nearly as possible for the discrepancy in the specific gravity between the oil used and that specified.

1912 Report. The conclusion reached upon an examination of the pavements by the government authorities, 6 years after it had been laid, was that: "The species will be tentatively grouped in accordance with the results of this inspection in the order of their value for creosote oil paving material as follows: (1) Long-leaf pine; (2) Norway pine, white birch, tamarack, eastern hemlock; (3) western larch; (4) Douglas fir."

In the **1914 Report**, covering the result of the fourth inspection, the order of efficiency of service according to species was practically the same as given above. The report goes on to say, however: "The most noteworthy result shown by this comparison is the sudden increase in the areas of local depressions below the general level of the sections, noted at the 1913 inspection, in all but the long-leaf pine and white birch sections. This was especially prominent in both larch sections, as noted first in the 1913 inspection. These two sections are rapidly becoming unserviceable. In 1910 depressions ½ in or more in depth were reported only in the Douglas fir sections which were replaced in 1911. In 1912 these depressions had appeared to a greater or less extent in all but the long-leaf pine, while by 1913 all sections showed considerable areas of deep depressions. The sections of white birch and long-leaf pine were all in about the same condition and were in much better shape than any of the other species. Eastern hemlock and tamarack had about the same percentage area of depressions and average wear and were in considerably better condition that Norway pine. Both of the western larch sections were in unsatisfactory condition, 25% and 35% of the areas, respectively, being below the general level of the pavement. These depressions

were very numerous and rendered the pavement rather rough. The deterioration of the larch blocks from now on will unquestionably be very rapid on account of these depressions. Blocks removed during the inspections were badly broomed and shattered."

Francis Wood's Specifications (9). "The timber from which the blocks are to be cut shall be carefully selected fourth Swedish, close grained, yellow deals, bearing the shipper's mark, and which must be described in the current Timber Trades Journal List. The annular rings shall not be less than 10 to the in, not more than 2 in of sapwood shall appear in any block, and the percentage of such in bulk shall not exceed 15. They shall also be free from large, loose or dead knots, shakes, or other defects, and shall not contain more than 5% of waney edges. Timber that has not been properly stored and become dry will not be accepted."

London Specifications: "It must be of a heavy resinous nature. Blocks showing blue sap or discolored wood will not be accepted. The blocks must be cut perfectly true in shape and size of the full specified depth after sawing, and free from large, loose or dead knots, waney edges, warps, shakes and other defects. One surface of every block must be free from knots."

Chicago Specifications: "All blocks shall be made of sound timber and shall be free from any defects which will be detrimental to the life of the block or interfere with the proper laying of the same. Each block shall have at least 66% of heart wood. The blocks shall be carefully protected from the effect of the sun and weather before and after treatment and until laid. The timber shall be that known to the trade as prime timber and of a texture permitting satisfactory treatment as hereinafter specified, and shall be subject to inspection at the works in the stick or at any time during the process of preparation or thereafter. The timber shall be sound, square-edged, free from bark, shakes, large or loose or rotten knots, red heart, worm or knot holes, or any other defects which will be detrimental to its strength or durability. No second growth timber or loblolly pine will be accepted. With southern yellow pine timber, the annual rings in the 3 in measured radially from the center of the heart shall average not less than 8 to the inch."

5. Size of Blocks

The principles governing the size of blocks are somewhat the same with wood as with stone, but they vary somewhat as regards the depth and the width. As timber is gotten out in exact sizes, it is a simple matter to specify the width of the blocks, they being cut from stock sizes of plank, and the same is true to a certain extent of the length of the blocks, as that corresponds to the width of the planks.

Width and Depth. The widths used in the United States are 3 in and 4 in, planks of this thickness being common for sale. Just which is the better width in a pavement is somewhat uncertain, altho it is believed that there is no very material difference. Three-inch blocks give more joints in the pavement, and for that reason afford a better foothold for horses; at the same time the greater number of joints gives more opportunity for wear, and on that account the narrow width is objectionable. The ordinary depth of blocks, too, is 4 in, and as, if the blocks are of the same width and depth pavers will invariably lay a few of them on the side, it is not advisable to have the width and the depth the same; so that, if a block with a width of 4 in is used, it is better to have the depth of the block 4½ in in order to avoid mistakes. It is remarkable how quickly a block laid flat can be picked out from the pavement at a glance, on account of the extra wear caused by the traffic coming upon the side of the fiber instead of upon the end. So far as actual wear is concerned, a block 3 in deep would undoubtedly last for 20 or 25 years on a residential street, but it is necessary that the pavement have a certain stability, which it cannot obtain with a shallow block, and a certain strength in the block itself, not only to sustain the weight of a load, but also to prevent its moving laterally, as it is un-

doubtedly a fact that a shallow block will expand much more easily than a deep one. In the United States, for ordinary streets, the depth is generally made 4 in, but sometimes on light traffic streets 3½ in.

In London the practice is to lay blocks 4 or 5 in in depth, but it must be remembered that the blocks used there are of softer material than American pine, and also that the traffic is much more severe. Four-inch blocks were being used in London in 1913, and the blocks previously referred to as seen on the Waterloo Boulevard, in Brussels, were only 3 in deep. Both the Paris and the London blocks wear down very appreciably before being replaced.

English Practice. Wood (9) states that the wear of best Swedish soft wood pavement in England is 0.061 in per annum per 100 tons per ft of effective width of roadway per day; and allowing a permissible total wear of 2.2 in, by figuring backwards he obtains the life of the pavement. So that he deduces that, when the traffic is equal to 3 000 000 tons per annum over an effective width of roadway, the life of the pavement will be 10.8 years. In speaking of the depth of the blocks he says: "The depth of the blocks is usually 5 in, but there is no reason why 4-in blocks should not be used in lighter trafficked roads. The method of selecting the depth of the block may be obtained by limiting the life of the proposed pavement to 12 years in the case of heavy traffic over 300 tons per ft width, 15 years over 100 tons per ft width, and 20 years under 100 tons per ft width. For example: Suppose the traffic was found to be 100 tons per ft width per day; the rate of wear would be 0.0615 in per annum; this multiplied by 20 equals 1.23 in, which added to 2.75 in equals 3.98 in. In this case a 4-in block would be sufficient. Any less depth than 3½ in off the saw would not be economical, and similarly, as may be gathered, any greater depth than 5 in would not give any greater satisfaction than a 5-in block." The above conclusion is evidently based upon 2.75 in as the minimum depth to be allowed a block under wear.

6. Preservatives

It is generally admitted that wood must have some chemical treatment if it is to be successfully used as a paving material. Wood has been treated chemically, in order to preserve its life in different structures, for many years. Many different kinds of treatment have been used and different chemicals employed, but the results have been such that it is generally considered by engineers at the present time that creosote oil manufactured from coal tar, all things considered, is the best. The object of the treatment is not only to prevent decay but also to keep the block stable, so that it will not expand too much in wet weather, or shrink and become loose in dry weather. For this reason the same principles will not prevail as if the material was to be used where preservation of the timber only was to be considered, as in piles, railroad ties, etc.

Required Life of Creosoted Wood Blocks. In most American cities the traffic on streets where wood would naturally be used is such that the blocks will wear out only after many years of use, so that a preservative is required that will not only preserve the wood for 5 to 25 years, but for even 40 years. If a block can be treated so that decay will be prevented for that length of time, there is no doubt that on the ordinary residential street in the ordinary city a wood pavement, properly laid, will last 40 years. A portion of Clinton Ave., Brooklyn, N. Y., was paved in 1903 with wood blocks; in the winter of 1913–1914 a portion of this pavement was taken up and exhibited at the Forest Products Exposition in New York. The blocks were found to have sustained a wear of only ¼ in. The traffic on the street was much more than that which would be had on the ordinary residential street, fully equal to the traffic on a good retail business street.

The Advantages of Creosoting (13) are as follows:

"1. A physical action: By the treatment a very greatly increased solidity

is effected by choking the pores of the wood, making it more solid, so that subsequent absorption of moisture is prevented to a great extent.

"2. A physiological action: The creosote imparted to the wood prevents germinal life, which would otherwise destroy the timber, as it developed within it. The preservatives used are chloride of zinc, sulphate of copper, etc, their action depending principally on their toxic properties. Creosote, however, it is stated, has the advantage of a well-marked smell which most of the lower animals dislike.

"3. A chemical action: The tar acids are not only antiseptic, but they possess the power of coagulating albumen. This latter action plays a very important part in the preservation of timber."

Kind of Preservative. Since 1910 there has been a great deal of discussion as to the nature of the creosote oil to be used, especially as to its specific gravity, some people claiming that an oil of a gravity of 1.03 or 1.05 should be used, as it would penetrate the blocks much more easily than the heavier oil, and that it is easier to obtain; others claim that the heavier oil should be used, as it is possible to get a satisfactory treatment with this oil and that it will remain in the blocks much longer than the lighter oil. This is a theory that has generally been accepted by engineers, as is shown by the specifications adopted.

The Function of the Preservative Treatment for wood paving, according to Hill (25), is to accomplish the following results: (1) Preservation from decay. (2) Mechanical filling of the pores, to prevent the absorption of fluids, which further accomplishes: (a) Elimination of expansion; (b) increase of resistance to wear; (c) maintenance of sanitary value. Creosote oil seems to meet these requirements better than any other preservative commonly used. The other preservatives are mostly water solutions, which are easily leached out of the wood, and thus lose their preservative effect. Moreover, being themselves largely composed of water, they do not prevent expansion in the blocks, do not increase their resistance to wear, and do not maintain them in a sanitary condition. The same requirements which have caused creosote to supersede other preservatives in wood paving call for a larger proportion of high distilling constituents in the creosote than is necessary in the preservation of timber for many other purposes."

Essential Qualities of Creosote Oils, as stated by Church (15b), are as follows: "It must be reasonably non-volatile in character, so as not to be rapidly lost by evaporation. It must be of sufficiently low viscosity at the temperature of impregnation so that the wood will not offer undue resistance to diffusion and penetration. It must be homogeneous in character, so that at all times a uniform product may be obtained. The chemical requirements of the oil should be as follows: It must be entirely insoluble in water, so that it will not be washed out of the wood, and so that it will resist to the highest possible degree the entrance of moisture into the treated fiber. It must be sufficiently antiseptic in character to preserve the wood against decay during the period of the mechanical life of the block."

Water-Gas Tar Creosote, according to Weiss (7), "may be produced which, on fractional distillation, will display a great similarity to coal tar creosote. There is a difference, however, in the constituents of the two creosotes, as shown by the difference in certain physical properties of fractions distilled from them at equal temperatures. Furthermore, water-gas tar creosote is distinctive in the absence of phenols and cresols, and usually in the presence of hydrocarbons of the paraffin group; it is not so antiseptic as coal tar creosote. Unfortunately, quantities of this oil are mixed with coal tar creosote, so that it is often impossible in practice to detect its presence. While this oil undoubtedly has considerable merit as a preservative of timber, there is not sufficient precise data available to warrant giving it the confidence which the coal tar product now enjoys."

Coal Tar Creosote, opinion by Weiss: "Tests made at the U. S. Forest Products Laboratory show the toxic limit of coal tar creosote to be between 0.2 and 0.4%. Very small amounts of it therefore protect wood from decay. In general, the lighter fractions are more toxic than the heavier fractions. They are also far more volatile

and when injected into wood by themselves evaporate at a rapid rate. The heavier constituents of coal tar creosote are therefore, in addition to being slightly toxic, of direct value in helping to retain in the wood these lighter oils."

Von Schrenk (45d) says: "It will not be necessary to dwell on the history of the use of coal tar creosote, nor to present proofs as to its value as a wood preservative. For years this substance has generally and justly been regarded as the best wood preservative, and the increasing quantities used plainly indicate that this is universally recognized."

Borough of Manhattan, New York City, Specifications: It has generally been accepted that the heavy oil called for in these specifications is not a direct distillate, but is formed by the mixing of fluid tar with the creosote oil. This, however, it is not supposed, will detract from its value.

"The oil with which the blocks are treated shall be at least 75% straight coal tar product and shall comply with the following requirements:

1. The specific gravity shall be not less than 1.08 and not more than 1.12 at 38° C (100° F).
2. It shall contain not more than 3% of matter insoluble in hot benzol and chloroform.
3. When subjected to distillation, according to the method hereinafter described, the amount of distillate based on water free oil shall be as follows: Up to 200° C, not more than 1.5%; up to 235° C, not more than 20%; up to 315° C, not less than 20 nor more than 50%. The fraction distilling between 235° and 315° C shall have a gravity of not less than 1.03 at 38° C (100° F)."

Chicago Specifications. A requirement, however, that does call for pure distillates of coal tar can be found in these specifications as given below. It is claimed by some that, while this may be a good oil, it is expensive and can be obtained only in small quantities. It seems, however, to give good satisfaction in the work, and the above, if valid, seem to be the only objections to it.

"It is required by this specification that the oil used shall be wholly a distillate oil obtained only by distillation from coal tar. No other material, of any kind, shall be mixed with it.

"The oil shall contain not more than 1% of matter insoluble in hot benzol and chloroform. Its specific gravity at 25° C (77° F) shall be not less than 1.08 and not more than 1.12.

"The oil shall be subjected to a distilling test as follows: The distillation shall be continuous and uniform, the heat being applied gradually. It shall be at a rate approximating 1 drop per sec, and shall take from 30 to 40 min after the first drop of distillate passes into the receiving vessel. The distillates shall be collected in weighed bottles and all percentages determined by weight in comparison with dry oil. When 100 g of the oil are placed in the retort and subjected to the above test, the amount of distillate shall not exceed the following: Up to 150° C, 2%; up to 210° C, 10%; up to 235° C, 20%; up to 315° C, 40%. The distillation of the oil shall be carried to 355° C. The residue thus obtained when cooled to 15.5° C (60° F) shall not be brittle, but shall be of a soft waxylike nature so that it can be readily indented with the finger. When a small portion of this residue is placed on white filter paper and warmed, the oil spot produced, when viewed by transmitted light, shall appear of an amber color. The tar acids of the distillate from 250° to 315° C must not be less than 6% of this distillate. The amount of the unsaponifiable oil, by sulphuric acid and caustic soda, in the distillate from 250° to 315° C must not exceed 3.5% of this distillate."

Am. Ry. Eng. Assn. Specifications for Grade 1 Oil. "The oil used shall be the best obtainable grade of coal tar creosote; that is, it shall be a pure product obtained from coal-gas tar or coke-oven tar and shall be free from any tar, oil or residue obtained from petroleum or any other source, including coal-gas tar or coke-oven tar; it shall be completely liquid at 38° C (100° F) and shall be free from suspended matter; the specific gravity of the oil at 38° C (100° F) shall be at least 1.03 when distilled by the common method, that is, using an 8-oz retort, asbestos covered, with standard thermometer, bulb ½ in above the surface of the oil; the creosote, calculated on the basis of the dry oil, shall give no distillate below 200° C, not more than 5% below

210° C, not more than 25% below 235° C and the residue above 355° C, if it exceeds 5% in quantity, shall be soft. The oil shall not contain more than 3% water."

The English Report (13) on wood block pavements, to the 3rd International Road Congress, stated that it is of the utmost importance that oil resulting from the distillation of coal tar shall be used, the oils resulting from the making of certain kinds of power gas being absolutely worthless for the preservation of timber. They give the following as the requirements for creosote oil suitable for treating paving blocks:

"The creosote is to be of the description known as heavy oil of tar, obtained solely by the distillation of coal tar, and consists of that portion of the distillate which comes over between 177° and 404° C (350° and 760° F). The specific gravity shall be not less than 1.035 nor more than 1.065 at 15.5° C (60° F), and as nearly as possible 1.05. The liquor must be free from any admixture with any oil or other substance not obtainable from such distillate. It shall contain not less than 20 nor more than 30% of constituents that do not distill over at 315° C (600° F). It must yield not less than 8% of tar acids. The creosoting liquor must become completely fluid when raised to a temperature of 38° C (100° F)."

London Specifications: "The creosote is the oil of tar known as creosote oil, free from all adulteration and impurities, generally free from ammoniacal water and containing not less than 5% of crude coal tar acids. The specific gravity is to range between 1.035 and 1.060 at a temperature of 15.5° C (60° F). It is not to deposit anything when kept at a temperature of 10° C (50° F) for 3 hr."

The Quantity of the Preservative is also a question upon which there is considerable difference of opinion and difference in practice. Like all other engineering questions, what is desired is to know just how much is required so that extra expense will not be incurred by asking for too much. If a pavement is to be subjected to a heavy traffic, where the blocks are liable to wear out before they rot out, it is obvious that a less amount of treatment can be used than if the traffic is to be very light. The early practice was to require a treatment of 20 lb per cu ft; this means a cost of from 50 to 60 cents per sq yd, so that if this amount can be materially reduced there will be a corresponding reduction in the cost of the blocks. Experiments have been made as to the amount required, but it must be remembered that not only present but future requirements must be taken into consideration. Because a 10-lb treatment is satisfactory today it does not follow that it will be in 10 years or longer, but a treatment must be used that will give the greatest economic life to the blocks, and consequently to the pavement. The cost of laying is the same, and if, by an additional 3 or 4 lb of preservative, an appreciable length of life can be given to the pavement, it will often prove to be true economy. It is believed that, as a general proposition, except on heavy traffic streets, a 20-lb treatment is the best. The Am. Soc. Mun. Imp. recommends 18 lb; the Assn. for Standardizing Paving Specifications, 18 lb; the City of Chicago requires about 16 lb per cu ft; the Borough of Manhattan, New York City, 18 lb per cu ft; and the Borough of Brooklyn, New York City, 20 lb per cu ft. In London the general requirement is for 10 lb per cu ft, and in Paris the old practice was 3 lb, but the more recent 10 lb per cu ft.

7. Manufacture of Creosoted Wood Blocks

The planks, if rough, are run thru a surfacer to get uniform thickness, and then sawn into blocks. This is essential in order to get straight courses in the pavement. The blocks are loaded into narrow gauge cage cars, which are charged into long horizontal cylinders which are closed tight. While in the cylinders the blocks are subjected to heat and vacuum treatment,

after which they are completely submerged in oil and subjected to sufficient hydraulic pressure to force a specific amount of preservative into the pores of the wood. The oil is then drained from the cylinder, which is opened, and the cars withdrawn, when the blocks are ready for shipment.

Pine will vary in weight per cubic foot from 40 lb in air-seasoned stock to 50 lb in green lumber. Forty-pound pine is too dry to make a satisfactory street block when treated with oil, whereas 50-lb pine has altogether too much water in it to secure the required penetration. It is therefore necessary to give a live steam treatment to both the light weight wood and the heavy wood to increase the water content of the former and to decrease the water content of the latter. About 2 hr treatment with steam is sufficient to moisten the dry wood, after which a vacuum of about ¾ hr should be applied to draw out as much air as possible from the wood cells. Oil should be run into the cylinder without otherwise breaking the vacuum so that when pressure is applied the wood cells receive oil without very much air in same. In the case of green wood the steam process should be longer than in dry wood, the object being to heat the blocks up to the boiling point of water. When the vacuum is applied a reasonable percentage of the hot moisture in the blocks vaporizes and is sent out of the cylinder along with whatever air escapes from the wood cells. The oil should be run into the cylinder as above. There will be a slight difference between the operation of treatment by various engineers, but it is usually found necessary to apply the pressure gradually in order to secure complete penetration and thoro diffusion. If the preservative used has an excess of free carbon, which makes a messy block, a subsequent bath of live steam while in the cylinder will clean the blocks off very nicely. After the blocks are treated it is desirable that they be shipped to the destination and laid as quickly as possible. Creosoting wood does not prevent entirely the absorption of moisture or the retention of same. It is therefore desirable to treat the blocks with a sufficient quantity of moisture contained in the walls of the cells to insure that the blocks do not shrink and to get them into the street as quickly thereafter as possible, so that they are laid in the pavement before they begin to shrink.

Treatment in a Vertical Tank Plant (20a). "A vertical tank plant for creosoting wood paving blocks has recently been installed at Terre Haute, Ind., by the Chicago Creosoting Co. These vertical retorts or tanks allow of material saving in the handling of material and present other advantages worth being noted by those interested in wood block paving. Briefly, these retorts are charged by disc conveyors, which carry the blocks direct from the block saw to the opened inlet head at the top of the retort being filled. One retort is filled while the other is engaged in impregnating its charge of blocks. When the blocks are to be taken out of a retort the outlet head is opened and the blocks flow directly into the cars to be loaded. The saving of labor and time by means of the loading and unloading equipment used for these retorts is the principal advantage gained in the operation of the new plant. A notable record for loading a car with creosoted blocks was recently made at this plant, when a 40-ft gondola railroad car was loaded in 2 min 5 sec with sufficient 3½-in blocks to lay 370 sq yd of pavement. This is at the rate of 2 solid cu yd of blocks per min. When horizontal retorts are used for treating paving blocks, the blocks are loaded into narrow-gauge tram cars at the saw. These cars are filled one at a time, until enough cars are loaded to make the desired length of train which is then switched into one of the horizontal retorts. After treatment the cars must be switched out of the retort, and dumped one at a time by a locomotive crane or other device into railroad cars. The vertical retort system eliminates all the narrow-gauge tracks and cars, the small locomotive, if one is used for switching the cars, the locomotive crane or other dumping device and all manual labor necessary for paving the blocks in the tram cars and for switching and unloading the cars. Another important advantage obtained with the use of the vertical

retorts is that such a retort furnishes a method of determining the exact volume of blocks being treated and the exact amount of oil absorbed by the blocks at each application. The manner in which these amounts are determined is explained in connection with a description of the creosoting process used at this plant."

The Bethell Method of Creosoting Timber is described by Weiss (7) as follows: "This process is named after John Bethell who took out patents in England in 1838. It is commonly referred to in our country as the full-cell process. Either green or seasoned timber can be treated by this process, creosote oil, dead oil of coal tar, being the preservative used. The timber to be treated is loaded upon steel cars or buggies, which are run into horizontal steel cylinders usually 7 ft in diameter by 132 ft long. Their length, however, varies from about 50 to 180 ft and diameter from 6 to 9 ft. If the timber is green, it is subjected to a bath of live steam for several hours, after which a vacuum is drawn by means of pumps. This also is held for one or more hours according to the judgment of the operator. If the timber is air seasoned, the steam bath is generally omitted. Creosote oil is then run or pumped into the cylinder and a pressure of 100 to 180 lb applied until the gauges show the desired amount of oil has been forced into the wood. The excess oil is then drained from the treating cylinder and the timber is allowed to drip for a short period, after which the process is ended and the charge is removed. Many treating engineers draw a vacuum in the cylinder after the excess oil has drained from it, as this tends to hasten the drip and dry the timber. The Bethell or full-cell process is considered the standard process of treating timber with creosote, and the most effective results in prolonging the life of wood have been secured by it. On account of the relatively large amount of oil which the ties absorb, the process is, however, the most expensive and for this reason several modifications have been made."

Treatments with Sulphate of Copper and Corrosive Sublimate. A firm in Portland, Me., treats blocks with this latter material. This consists in steeping the timber in a solution of bichloride of mercury by the open tank cold bath method. These blocks are used to quite an extent on bridges, as they are extremely light, the treatment adding very little to the weight of the blocks. In Brussels in 1913 blocks were treated with sulphate of copper, but to so slight an extent that it seemed doubtful if the treatment could add very much to the life of the block.

Municipal Plant at Paris. The process of paving with wood in Paris is carried on in a different way from that of any other city in Europe, as the blocks are manufactured and furnished by the municipality to the contractor. The city has a very large and efficient plant, in a central location. The timber is unloaded from the cars directly to piles by means of an electric tiering machine. These piles are approximately 40 ft high, most of them kept under glass roofs. The blocks are sawed by an electrically driven machine, which cuts 16 blocks at once, the sticks being fed automatically to the saws and the blocks automatically discharged, with the grain up, to the inspection table. From the table, previous to 1913, they were loaded into very small iron treating cars, five or six of which were run under the creosote oil tank, where each car was filled by gravity with an oil at 80° C (176° F). After 20 min the oil was drawn off from the bottom of the cars and the blocks taken to the storage yard. The average absorption was 3 lb per cu ft, and naturally the penetration was very slight. It is not surprising that the blocks decayed before wearing out, but at first sight it is very surprising that they did not continually buckle and bulge. In 1913 a plant was installed in Paris which would treat the blocks in practically the same way as are those of London, the idea being to impregnate the blocks with 10 lb of oil per cu ft, not so much to increase the life of the blocks as to prevent bulging. The oil used had a specific gravity of 1.08. One of the engineers in Paris, in speaking of the bulging of wood pavements, said it was bound to occur and that the only thing to do was to take the pavement up and relay it. If, however, a more thoro treatment is given to the blocks, as would be the case if the plans of 1913 were carried out, the bulging would undoubtedly be materially less. The material of the blocks in Paris is such that, as the blocks wear, they batter down, with rough edges, so that when they are taken up from the heavy traffic streets they have these edges trimmed with a specially designed machine, after which the blocks are relaid on lighter traffic streets. Sometimes the surface of the block is so rough that it is necessary to saw off the entire top. This is done upon the street if the blocks are to be immediately used. During 1911 over 3 000 000 blocks were treated in this way. In 1911 the municipal plant manufactured

20 378 000 blocks, of which 313 000 were creosoted under pressure. The total number of blocks made would lay about 465 000 sq yd of pavement.

Chicago Specifications: "The blocks shall be placed in an air-tight cylinder where, by means of steam and the vacuum pump, the sap in the blocks will be vaporized and the moisture in them removed. During the process of steaming a vent shall be kept open in the cylinder to permit the escape of water, air and condensed steam in the cylinder. After the heating or steaming period, the drain or vent in the bottom of the cylinder shall be opened and all moisture removed from the cylinder. During the vacuum period the temperature in the cylinder must be above the boiling point of water under existing vacuum. When the cylinder is thoroly drained, a vacuum of not less than 20 in shall be maintained. When the blocks are thoroly dry the cylinder shall be filled with oil destroying a vacuum of not less than 20 in and pressure shall then be applied and increased gradually to not more than 200 lb per sq in and maintained until 16 lb of oil have been forced into and retained in each cubic foot of timber and until the oil has impregnated the blocks to the satisfaction of the Board of Local Improvements. The pressure period on the oil shall be continuous and of a duration of not less than 3 hr. After the surrounding oil has been removed, the blocks shall remain in the closed cylinder for a period of 30 min to allow the excess oil on the surface of the blocks to drain off. The oil thus drained off shall be forced back into the treating tank in order to determine the amount of impregnation. In the process of treating the blocks, a correction must be made for any water contained in the cylinder. Compensation shall also be made for leaks and other wastes of oil that may occur during treatment. If, in the treatment of the blocks, more oil is injected per cubic foot of timber than is called for in the specifications, such excess oil must not be removed. The temperature of the oil after entering the cylinder shall be not lower than 74° C (165° F). The cylinder shall be provided with sufficient steam coils to fully maintain this temperature thruout injection. The oil tanks and cylinder in which the blocks are treated shall be equipped with the necessary gauges, thermometers and draw-cocks in order to facilitate a thoro inspection of the materials and treatments. The cylinder shall be equipped with the proper connections and apparatus for artificially seasoning timber before the impregnation with the creosote oil. The plant shall be provided with proper means for obtaining the absolute measurement and weight of all oils entering the cylinder and the amount of oil absorbed by the blocks."

Kansas City, Kan., Specifications: "The method of treatment must be thoro and up-to-date, containing the necessary air-tight cylinders, steam pipe, boilers, vacuum and force pumps, tanks, gauges, etc, and shall be carried on in accordance with the best modern practice under the joint supervision of the manager of the plant and the city engineer or his representative. During the process of treatment, the blocks shall be subjected to a thoro steaming of from 1 to 4 hr, as required by the city engineer, and then to a vacuum of from 22 to 26 in of mercury, during which time the temperature in the cylinder shall be at all times above the boiling point of water under the existing vacuum. After the moisture and sap extracted by the steaming and vacuum have been drained from the cylinder, the vacuum shall be destroyed by the admission of the creosote oil to completely fill the cylinder, and not by the admission of air. Pressure of from 100 to 200 lb per sq in shall then be applied and maintained until 16 lb for traffic streets and 18 lb for residence streets of the creosote oil have been forced into and retained in each cubic foot of timber. The pressure shall be gradually applied, and if in the opinion of the city engineer better results can be obtained, the maximum allowable pressure may be fixed at any point less than 200 but more than 100 lb per sq in, and maintained at that figure long enough for the wood to absorb the specified amount of oil. The temperature of the oil after entering the cylinder shall at no time be less than 66° C (150° F) or more than 116° C (240° F). The blocks, after treatment, shall show a satisfactory penetration of oil thruout. All blocks which are in any way defective or which have been badly warped or checked in the process of treatment shall be rejected. Before removing the charge from the cylinder, the blocks shall be given a steam bath lasting at least ½ hr to clean off all the surplus oil. The manufacturer shall furnish all appliances necessary for tests and all labor which may reasonably be required in removing material for examination. The oil tanks and treating cylinders shall be provided with necessary gauges, thermometers, draw-off cocks, etc, affording adequate means for determining the absolute weight of oil retained in

the blocks. The contractor shall furnish a copy of the plant record showing a complete statement of each operation in the creosoting process."

London Specifications: "The blocks are to be creosoted, the temperature of the oil being not less than 66° C (150° F), the creosote to be forced into the blocks at a pressure of not less than 80 lb to the sq in, and to the extent of 10 lb of oil to the cu ft of timber. Before applying the pressure the cylinder is to be exhausted to a vacuum equivalent to 20 in of mercury."

English Practice. The report (13) to the 3rd International Road Congress of English engineers states that the best known process for creosoting timber is BOULTON'S. While it is claimed that wet timber can be successfully creosoted by this process, it is preferred that the timber should be seasoned in the blocks for at least 6 months before being cut up into the sizes of the blocks for pavement. The treatment is described as follows: "The blocks are placed in closed iron cylinders to which a steam dome is fitted, and a condenser is also fitted to the air pump. The pump is started, and a vacuum of 10 to 15 lb per sq in is obtained, and oil at a temperature of 100° C (212° F) is then forced into the cylinder at a pressure of from 50 to 60 lb. The creosote oil at this temperature forces the air and moisture out of the timber in the form of steam, and the air pump withdraws this air and steam from the dome."

The following requirement for treatment is given by WOOD (9): "The creosote to be forced under pressure into the blocks until they have absorbed an amount of 10 lb to each cu ft, and in such a manner that any block split open will show the creosote to have penetrated right thru. The creosote is to be a liquid heavy oil of tar, commonly called creosote, and is to contain not less than 8% of tar acid. It will be subjected to analysis, and the contractor is only to use such as may be approved by the analyst."

Treatment in Berlin. The wood blocks are immersed in a bath of carbolized coal tar, at room temperature, and allowed to remain 15 or 20 min. This process is said to give good satisfaction.

Inspection at Plant. Before the blocks are put into the cylinder, the inspector should select a few average blocks from each cage and measure out from the same exactly 1 cu ft. This is easily done by laying the blocks in a single row, end to end, until the requisite length is covered, the last block being cut to exact length with a hatchet. For instance, blocks 4 in deep by 4 in wide will take 9 in in length for 1 cu ft. This average cubic foot should be weighed, placed in a wire basket, and subjected to the same treatment in the cylinder as the rest of the charge. When the cylinder door is opened, this cubic foot should be taken out and weighed to determine whether the charge as a whole has received the requisite amount of oil per cubic foot. If the weight is all right, the blocks should be split with a cleaver to see whether the penetration and the diffusion are satisfactory. It is possible to get 20 lb of oil per cu ft in blocks by very quick treatment, where the penetration and the diffusion will show bad, whereas 10 lb per cu ft by more careful impregnation may show good penetration and diffusion. The results obtained by the cubic foot test as outlined above should always be taken in connection with the total quantity of oil used, as shown by the tank readings, and the two should correspond very closely.

Test for Water and Oil Content. Claims are sometimes made by creosoting companies as to the amount of moisture removed in the cylinder by the high vacuum treatment and allowances asked for, which may or may not be legitimate. Ordinarily the inspector can determine this matter for himself and prove beyond any question exactly what the preliminary treatment has done. This method is little known, but should be used from time to time as a check on the operation. The test is made as follows:

Two cubic feet are selected from the untreated blocks as an average; it is easy to pick out samples so that each cubic foot is made up of sister blocks. Both cubic feet are weighed, and will ordinarily show the same weight per cubic foot. One cubic foot

is put into the cylinder as outlined above; the other cubic foot is taken to a wood drilling machine and a large number of borings made quickly. These borings are thoroly mixed and 100 g of the borings are carefully weighed and thrown into a copper distilling apparatus with a sufficient quantity of xylo to thoroly submerge same. The xylo and borings are then boiled in the apparatus, and all the water in the wood distills over and separates at the bottom of the receiving test tube, which should be graduated in cubic centimeters. The whole test may be made in 20 min. The number of cubic centimeters of water then in the test tube is the percentage of water contained in the untreated blocks. From this the dry weight per cubic foot of the untreated blocks is determined. After the charge is treated, the treated test cubic foot is bored in the same manner as the untreated one, and the percentage of water in the treated blocks determined in the same manner. Thus the inspector knows the weight of 1 cu ft of treated block, the weight of the dry wood, the weight of the water in the blocks, and, by the difference, gets the exact weight of the oil in the same.

Defects in Wood. Wood block plants receive lumber in the shape of planks. These planks should be sorted at the works; first, to permit lumber of approximately the same weight per cubic foot to be treated by itself; and, secondly, to throw out culls or rejects. The usual defects are: poor manufacture, the planks being too thin or having a tapered surface; split planks, wind shakes, loose and rotten knots, wane, large worm holes, and red heart. Red heart may not always be detected in the plank before it is sawn; the inspector, therefore, should particularly look over the cut blocks, as red heart shows very plainly in first cut lumber. Red heart is probably the most important defect to be caught by the inspector at the works, as most of the other defects can be discovered before the blocks get into the pavement.

8. Specifications for Wood Blocks

The following specifications were adopted in 1916 by the Am. Soc. Mun. Imp. For sections covering the construction of the pavement, see Art. 10. Specifications relative to the practice in several American and European cities pertaining to physical properties of wood blocks will be found in Art. 4; to size of blocks in Art. 5; to preservatives in Art. 6; and on manu facture of wood blocks in Art. 7.

"**Timber.** The wood from which the blocks are to be manufactured shall be southern yellow pine, Douglas fir, tamarack, Norway pine, hemlock or black gum. Only one kind of wood shall be used in any one contract. The blocks must be sound and must be well manufactured, square butted, square edged, free from unsound, loose, or hollow knots, knot holes and other defects such as shakes, checks, etc, that would be detrimental to the blocks. The number of annual rings in the 1 in which begins 2 in from the pith of the block shall not be less than six, measured radially, provided, however, that blocks containing between five and six rings in this inch shall be accepted if they contain 33.3% or more summerwood. In case the block does not contain the pith, the 1 in to be used shall begin 1 in away from the ring which is nearest to the heart of the block. The blocks in each charge shall contain an average of at least 70% of heartwood. No one block shall be accepted that contains less than 50% of heartwood.

"**Size of Blocks.** The blocks shall be from 5 to 10 in long, but should preferably average two times the depth; they shall be * in in depth. They may be from 3 to 4 in in width but in any one city block all of them shall be of uniform width. A variation of 1/16 in shall be allowed in the depth, and 1/8 in in the width of the blocks from that specified. In all cases the width shall be greater or less than the depth by at least 1/4 in.

*The Committee recommends blocks 4 in in depth for very heavy traffic streets; blocks 3½ in in depth for moderate traffic streets. For light traffic streets blocks 3 in in depth may be used, but where 3-in blocks are used no block shall be longer than 8 in.

"**Preservative.** The preservative to be used may be either a coal tar paving oil or a coal tar distillate oil as herein specified.

"COAL TAR PAVING OIL. The oil shall be a coal tar product of which at least 65% shall be a distillate of coal-gas tar or coke-oven tar, and the remainder shall be refined or filtered coal-gas tar or coke-oven tar. It shall comply with the following requirements:

1. It shall not contain more than 3% of water.
2. It shall not contain more than 3% matter insoluble in benzol.
3. The specific gravity of the oil at 38° C (100° F) shall not be less than 1.07 nor more than 1.12.
4. The distillates based on water free oil shall be within the following limits: Up to 210° C, not more than 5%; up to 235° C not more than 25%. The residue above 355° C, if it exceeds 35%, shall have a float test of not more than 80 sec at 70° C (158° F).
5. The specific gravity of the fraction between 235° and 315° C shall not be less than 1.02 at 38°/15.5° C (100°/60° F). The specific gravity of the fraction between 315° and 355° C shall not be less than 1.09 at 38°/15.5° C (100°/60° F).
6. The oil shall not yield more than 10% coke residue.

"COAL TAR DISTILLATE OIL. The oil shall be a distillate of coal-gas tar or coke-oven tar, and shall comply with the following requirements:

1. It shall not contain more than 5% of water.
2. It shall not contain more than 0.5% of matter insoluble in benzol.
3. The specific gravity of the oil at 38° C (100° F) shall not be less than 1.06.
4. The distillates based on water free oil shall be within the following limits: Up to 210° C, not more than 5%; up to 235° C, not more than 15%. The residue above 355° C, if it exceeds 10%, shall have a float test of not more than 50 sec at 70° C (158° F).
5. The specific gravity of the fraction between 235° and 315° C shall not be less than 1.02 at 38°/15.5° C (100°/60° F). The specific gravity of the fraction between 315° and 355° C shall not be less than 1.09 at 38°/15.5° C (100°/60° F).
6. The oil shall yield not more than 2% of coke residue.

"WATER-GAS TAR.* The preservative shall be refined water-gas tar and shall comply with the following requirements:

1. The specific gravity shall be not less than 1.12 nor more than 1.14 at 38° C (100° F), referred to water at the same temperature.
2. Not more than 2% shall be insoluble by hot extraction with benzol and chloroform.
3. On distillation, which shall be made as hereinafter described, the distillate based upon water free oil shall be within the following limits:

   Up to 210° C, not more than 5%
   Up to 235° C, not more than 15%
   Up to 315° C, not more than 40%
   Up to 355° C, not less than 25%
4. The specific gravity of the total distillate below 355° C shall not be less than 1.00 at 38° C (100° F), referred to water at the same temperature.
5. The oil shall not contain more than 2% water, and due allowance shall be made for all water and insoluble foreign matter it may contain, by injecting a corresponding additional quantity into the blocks.

"**Treatment.** The timber may be either air seasoned or green, but should preferably be treated within 3 months from the time it is sawed. Green timber and seasoned timber shall not, however, be treated together in the same charge. The blocks shall be treated in an air-tight cylinder with the preservative heretofore specified. In all cases, whether thoroly air seasoned or green, they shall first be subjected to live steam at a temperature between 104° and 116° C (220° and 240° F), for not less than 2 hr

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*In view of the fact that some cities are using a water-gas tar, your Committee deems it advisable to suggest a specification for their guidance. This specification is the one submitted and agreed to by C. N. Forrest, Chemist of the Barber Asphalt Paving Co., and W. H. Fulweiler, Chemist of the United Gas Improvement Co.

nor more than 4 hr, after which they shall be subjected to a vacuum of not less than 22 in, held for at least 1 hr. While the vacuum is still on, the preservative oil, heated to a temperature of between 82° and 104° C (180° and 220° F), shall be run in until the cylinder is completely filled, care being taken that no air is admitted. Pressure shall then be gradually applied not to exceed 50 lb at the end of the first hr, nor 100 lb at the end of the second hr and then maintained at not less than 100 lb nor more than 150 lb until the wood has absorbed the required amount of oil.*

"After this a supplemental vacuum shall be applied, in which the maximum intensity reached shall be at least 20 in and shall continue for a period of not less than 30 min. If desired, this vacuum may be followed by a short steaming period. In any charge the blocks shall contain at least 16 lb of water free oil per cu ft of wood at the completion of the treatment. The blocks after treatment shall show satisfactory penetration of the preservative, and in all cases the preservative must be diffused thruout the sapwood. To determine this, at least 25 blocks shall be selected from various parts of each charge and sawed in half at right angle to the fibers thru the center, and if more than one of these blocks show untreated sapwood the charge shall be retreated. After retreating, the charge shall again be subjected to a similar inspection. The surface of the blocks after treatment shall be free from deposit of objectionable substances, and all blocks that have been materially warped, checked or otherwise injured in the process of treatment shall be rejected.

"Method of Sampling Preservative. CONTINUOUS DRIP SAMPLE. When the oil is being loaded or discharged by means of a pump, the following methods shall be used: The pipe lines thru which the material is being pumped shall be tapped on the discharge side of the pump, preferably in a rising section of the pipe line. The sample shall be taken by means of a ½-in pipe, extending half way to the center of the main pipe, and the inlet of the ½-in pipe shall be turned to face the flow of the liquid. This pipe shall discharge into a barrel or drum of 50 to 100 gal capacity, and the plug cock regulated so as to secure a continuous, uniform stream during the entire pumping of the shipment. The barrel, or preferably the iron drum, should be provided with a small steam coil sufficient to keep the contents thoroly liquid. The temperature shall not exceed 49° C (120° F). The contents of the barrel or drum shall be very thoroly agitated, and small samples for testing taken immediately. The amount of the drip sample collected shall be not less than 1 to 1000 gal of material handled, excepting in the case of large boat shipments, where a maximum of 100 gal will suffice.

"STORAGE TANK SAMPLES. In sampling from storage it is necessary to secure samples from different levels, and where possible this may be done by means of small outlet cocks, at regular intervals, from the top to the bottom of the storage tank. In such cases about 1 gal of tar or oil shall be drawn from each outlet cock and thoroly mixed and a portion taken for testing. The stream from each cock shall be always allowed to flow for sufficient length of time to enter the outlet pipe and nipple, before commencing to collect the sample. When tanks have no outlet cocks, a vessel having a string attached to the cork may be lowered to measured depth, representing a number of different levels in the tank, and the cork removed when the vessel has reached the proper level. These samples shall be combined for an average as above.

"Handling Blocks After Treatment. Blocks shall preferably be laid in the street as soon as possible after being treated. If they can not be laid within 2 days, provision shall be made to prevent them from drying out by stacking in close piles and covering them, and, if possible, sprinkling them thoroly at intervals. The blocks shall be well sprinkled, under the direction of the purchaser, about 2 days before being laid.

"Inspection. All material herein specified and processes used in the manufacture of the blocks therefor shall be subject to inspection, acceptance or rejection at the plant of the manufacturer, which shall be equipped with all the necessary gauges, appliances and facilities to enable the inspector to satisfy himself that the requirements of the specifications are fulfilled. The purchaser shall have the further right to inspect the blocks after delivery upon the street, for the purpose of rejecting any blocks that do not meet these specifications, except that the plant inspection shall be final with respect to oil and treatment."

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*This treatment is recommended for yellow pine only. It is probably also suited to Norway pine, hemlock, black gum and tamarack, but not Douglas fir. Further recommendations on the treatment of these species are reserved for the future.

CONSTRUCTION

9. Laying the Pavement

The Foundation for a wood block pavement should be of Portland cement-concrete, mixed in standard proportions. The surface of the concrete should be somewhat smoother than for granite, as it is more important that the wood blocks should be well bedded than should stone blocks, as they will break more easily. In America the practice is to lay a cushion of either sand or mortar upon the surface of the concrete before laying the blocks, so that they will become well bedded. Most cities specify either a sand or a mortar bed cushion, reserving the right of course to specify whichever one is desired for any particular street.

Cement Mortar Bed. It is believed that the mortar bed is the better, because, after the pavement is once laid, it should be in such condition that the individual blocks will not settle. If blocks are laid on a sand cushion, the pavement is rolled or rammed, as the sand must be of slightly varying depths; the blocks will get an uneven pressure under the roller or rammer, and so, under traffic, where the wheels strike the individual blocks, depressions are liable to occur, making the pavement slightly undulating. This is undesirable and should be avoided if possible. If a mortar bed is used the blocks are thoroly imbedded in it by the action of the roller or rammer, and, tho used dry, it soon sets, and the blocks become firmly fixed on a hard base. The cushion is practically impervious to water, so that the cushion can never be washed away by water getting under the blocks, as sometimes happens with the sand cushion. When a sand cushion is used it is generally 1 in thick, and the mortar bed is generally made ½ in thick, mixed in the proportion of 1 : 1 or 1 : 2, according to the ideas of the engineer. The general practice in the United States seems to be to use the mortar bed. If this is used, after it sets, the pavement becomes as solid as if it had all been laid at one time.

In Europe, however, the practice is different in all cities using wood block pavement to any extent. There the concrete is either so laid that it will have an absolutely smooth surface, or it has an upper layer, perhaps ½ in in thickness, formed of finer materials, so that the surface is easily made smooth. The concrete is laid with a straight-edge, so that it is absolutely true to the desired crown, and trowelled in such a way that the surface is as smooth as the ordinary cement walk. In some instances blocks are laid directly upon the concrete and in others upon a thin coating of pitch, which is first spread upon the concrete surface. A small amount of pavement, laid on the concrete with and without this pitch coating, was put down in Chicago in the latter part of 1914. It has, however, not been in use long enough to demonstrate its action. The wood pavements of Europe are as a rule softer than those of America, so that they would naturally be more resilient, but even the hard woods of Australia are laid directly upon the concrete base.

Petrograd. The wood pavements of this city are undoubtedly in a class by themselves. The timber used is generally pine, altho spruce is used to a certain extent. The blocks are manufactured by hand and by machinery, the hand-made blocks costing about 84 cents per sq yd and the machine-made about 63 cents per sq yd, according to the amount manufactured each year. It is stated, however, that, as there is no competition in the manufacture of machine-made blocks, the price of them is kept the same as that of hand-made blocks. In the construction of the pavement the blocks are laid on concrete and on wood. A 1 : 4 : 6 broken stone concrete is laid about 6 in deep and covered with a layer of 1 : 1 cement mortar about 1 in thick. The blocks are laid closely together. The wooden foundation consists, first, of pine logs 9 in in diameter laid across the street a distance of about 39 in apart. On top of the logs is laid a flooring of planks 2.4 in thick and from 7 to 8 in wide. These planks are fastened to the logs by iron nails. The planks are generally laid with an

open joint so that the water can pass thru them to the soil beneath, where drains are constructed connecting with the nearest reservoir. The pavement when completed is covered with two coats of coal tar or rosin, after which a thin layer of sharp, coarse sand is thrown over it. Occasionally the lower parts of the blocks are dipped in tar before being laid. The cost of the pavement as above constructed is $0.99 per sq yd for the pavement proper; with concrete foundation, $2.45 per sq yd, and with the wooden foundation, $1.77 per sq yd. Figs. 1 and 2 show construction on wooden foundation in Petrograd.

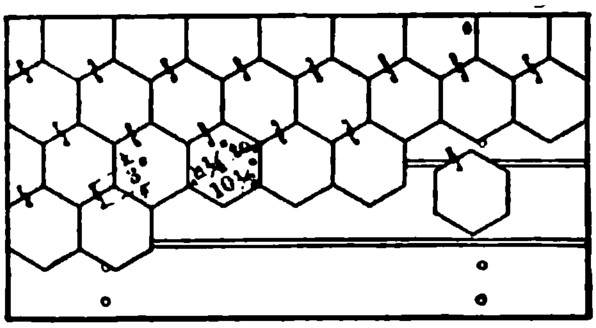


Fig. 1

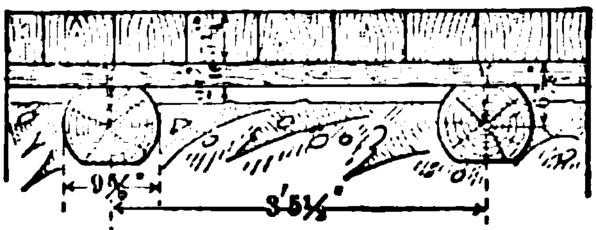


Fig. 2

Vroublensky (45) says: "The wood blocks are soon crushed and ground down and absorb liquid filth, diffusing a bad smell and possibly serving to spread infectious diseases. Also in the interstices between the blocks dirt collects. With wooden foundations, the pavement seems to be still more incomplete in the sanitary sense, as the dirt percolating thru it soaks into the ground, dirtying and infecting it. Finally, organic dust is formed by the wear of the pavement, which, rising during the dry time of the year, infects the air and makes it injurious to health. It is evident that the methods employed in Petrograd cannot be recommended."

Laying the Blocks. The fundamentals of the best American practice are described in the 1916 specifications of the Am. Soc. Mun. Imp. (see Art. 10).

Borough of Manhattan, New York City, Specifications provide for practically the same procedure as those of the Am. Soc. Mun. Imp., except that they do not call for a row of blocks to be laid parallel to the curb; they provide that joints shall be broken by a lap of not less than 2½ in, and they do not require any expansion joint. Where car tracks exist on the street they provide that the spaces between the web of the rail and the blocks and directly under the head of the rail shall be filled with a stiff mortar composed of one part of Portland cement and three parts of clean, sharp sand; the mortar to be carefully struck so that it will not project beyond the vertical plane of the edge of the rail head, and to be kept in position until the pavement is laid.

Chicago Specifications require that: "The blocks shall be laid in parallel courses across the roadway at an angle of approximately . . . . degrees from the center line thereof, except at the intersections of all alleys, where they shall be laid at right angles with the center lines thereof. On intersections and junctions of lateral streets, the blocks shall be laid at an angle of 45° with the line of the street, unless otherwise ordered by the Engineer. The blocks shall be laid with the fiber of the wood running in the direction of the depth. Gutters shall be constructed as directed by the Engineer. The courses shall break joints alternately by a lap of not less than 2 in and the blocks shall be driven together except where joints for expansion are constructed. The blocks, when set, shall be rolled with a steam roller weighing not less than 5 tons, until firmly bedded and brought to a uniformly even surface. After rolling, all imperfect blocks shall be removed and replaced by perfect blocks. Broken blocks shall not be used except to break joints in starting courses and in making closures. If the blocks that have been laid should become wet before the filler is applied, they must be taken up and reset at the contractor's expense, if the Engineer so directs. In no case will teams be allowed on the work before the wearing surface is completed."

The Brooklyn, N. Y., Specifications provide that: "The joints between the blocks shall be not more than ¼ in in width when bituminous filler is used, and not more than ⅛ in in width when sand filler is used. The blocks shall be laid by the pavers standing upon the blocks already laid, and not upon the bed of mortar. The blocks shall be laid in straight courses, at right angles with the line of the street, except at street intersections, where they will be laid diagonally, as the Engineer may direct. All longitudinal joints shall be broken by a lap of not less than 3 in."

Provisions for Expansion. When the creo-resinate wood blocks were

first laid in Brooklyn no provision was made for an expansion joint, it being thought that if the blocks were so treated that they would not absorb more than 3% of water, when dried for 24 hr at a temperature of 38° C (100° F) and then immersed in water for 24 hr, there would not be sufficient expansion to do any harm. This was found to work out in practice, and no material amount of bulging or swelling occurred in the pavements so laid. When, however, the rosin was dropped from the preservative and an oil used, it was deemed best in most cities to provide for an expansion joint, altho this procedure has not been followed in the Borough of Manhattan, New York City. Most engineers think that it is not possible, and perhaps not desirable, to treat a block so as to make it absolutely waterproof, and if a block can be so treated as to prevent decay and at the same time not have too much expansion, it may be better to lower the amount of treatment in the blocks and so reduce expense. It must be remembered, however, that in order to expand from side to side across the street to any appreciable extent the blocks must move on the base, which is undesirable, if not impossible if the blocks are imbedded in a mortar cushion. The general practice in America, however, is to provide for an expansion joint lengthwise of the curb and fill the same with some bituminous material. In some instances joints have been laid crosswise of the pavement. This, however, is not the general practice, and, unless absolutely necessary, is not desirable, as it gives a wide joint, and therefore causes undue wear.

In Europe, the practice is always to provide an expansion joint near the curb. This is more necessary there than in America, as the blocks do not have a heavy treatment. On one street where wood block was being laid in London in 1913, two rows of the blocks were being laid parallel to the curb, with two expansion joints about 1 in wide, one adjacent to the curb and the other between the rows of blocks, these being filled with clay or some other similar material. Such filling for expansion joints is more common in Europe than the use of bituminous material. In Paris the expansion joint is sometimes filled with an oblong hollow device made of thin sheet steel, about 3 in high and 1¼ in wide; this is placed in the joint, and is supposed to be elastic enough to give under the pressure of the expanding blocks and so prevent bulging.

The Specifications of the Borough of Brooklyn, New York City, provide that when bituminous joints are specified, the joints are to be immediately filled with a hot filler, but with sand joints the pavement is to be rolled. Before the blocks are laid, it is specified that a board 5 in in width, 1 in thick at top and ¾ in thick at the bottom, shall be placed along and against the curb, the blocks at the beginning and the end of each course to be set against these boards. After the blocks are rolled, the boards are withdrawn, and the spaces between the blocks and the curb filled with a bituminous filler. A joint ½ in in width shall be left along the rails of the trolley tracks, and this joint shall also be filled with a bituminous filler. It is also specified that after the joints have been completely filled and the pavement rolled a layer of sand shall be spread over the surface and allowed to remain there for 10 days. It is also provided that if at any time during the maintenance period the street should require sand for the purpose of absorbing surplus oil or joint filler, it shall be supplied by the contractor.

The Chicago Specifications provide that on each side of the roadway a longitudinal joint shall be formed by placing a 1½-in board on edge against the curb. The blocks shall be firmly bedded against said boards. The boards shall remain in place until the blocks are rolled, and immediately preceding the application of the filler they shall be carefully removed without disturbing the adjacent blocks.

As an instance of a special case of laying blocks, when the Strand, in London, was paved with wood, in about 1901, it was desired to have the work done with as little disturbance to traffic as possible. The portion paved was from Trafalgar Square to Charing Cross, some 1200 or 1300 ft. The work was done from curb to curb,

proceeding without stopping day and night, and, as was stated by the Engineer, the blocks were laid upon the concrete when it was so soft that the pavers had to have planks to stand on so as not to deform the concrete. The entire work was completed in 3 days. Before being thrown open to traffic it was covered with about 2 in of coarse gravel. The Engineer also stated that, while he had some misgivings about how the work would turn out, it was satisfactory in every respect. In 1914, when this street was repaved, one-half of the street only was done at one time.

Joint Filling. Sand. The question of filling joints in wood pavement has received as much discussion as that for stone block pavement, and the materials used are practically the same. The creo-resinate pavements laid in Brooklyn, N. Y., had all the joints filled with sand, and after a little traffic they were completely filled, and undoubtedly as nearly waterproof as if a bituminous or cement grout filler had been used. It can be said, too, of a sand filler, that if the blocks bleed, the sand in the joints will absorb a certain amount of the oil; on the other hand, when the sand is closely packed it cannot be compressed, and therefore will not take up any expansion of the blocks. Where the traffic is quite heavy it is believed that a sand joint filler is as good as any other, if not better.

Cement Grout. This filler has been used to a certain extent, but it does not seem to have much to commend it. The mortar cannot adhere to any extent to the wood, as it can to stone, and the film of cement, after it has set, must be very thin and liable to break under traffic, so that the filler will be little better than sand. It, too, requires that the street shall be closed for a sufficient length of time to allow the mortar to thoroly set; otherwise the result before spoken of will ensue.

Bituminous Filler. A bituminous filler is probably used more generally in wood pavements than any other kind. It has one great merit in that every joint between the blocks is really an expansion joint so that it will take up a certain amount of the expansion in the blocks and thus have a tendency to prevent bulging. That it will not entirely do this is evident from experience. But it adds to the trouble if the blocks bleed to any extent, as, if the bleeding is caused by expansion, the surplus that is used for the filler is crowded to the surface, adding materially to the amount that exudes from the blocks themselves.

The general practice in Europe is to fill the joints with some bituminous material, but cement grout is used to a certain extent, and sometimes a combination of both, the lower part of the joint being filled with bituminous material and the upper part with cement to prevent any liability of trouble from stickiness.

10. Specifications for Construction

The following specifications were adopted in 1916 by the Am. Soc. Mun. Imp. For sections covering physical properties of wood blocks and preservatives, and method of manufacture, see Art. 8. Specifications relative to the practice in several American and European cities pertaining to details of construction will be found in Art. 9.

"**The Foundation** for the pavement shall be of cement-concrete made in accordance with the specifications for concrete paving foundations and shall be * inches in thickness. At no place shall the surface of the finished concrete vary more than ½ in from the given grade.

"**Cushion.** Bituminous. Over the concrete foundation laid as specified above shall be spread a layer of cement mortar composed of one part Portland cement to two parts of sand. This mortar shall be of such a consistency that it may be easily spread,

*The Committee recommends that the concrete base be at least 5 in in thickness and under heavy traffic 8 to 9 in is recommended.

and must be applied to the surface of the concrete not more than 45 min after the placing of the concrete foundation. This mortar must be struck by templets to a surface parallel to the grade and contour of the finished pavement in such a manner that when the blocks are set the surface of the pavement shall conform accurately to the established grade. After this mortar coating is thoroly set and hardened, it shall be painted with a coal tar pitch as specified under bituminous filler, or other suitable waterproofing paint. The paint coat must be applied as thin and as smoothly as possible, and at no place shall it be over ⅛ in in depth. The blocks shall be laid as specified below directly on this paint coat within at least 30 min after it has been applied.

"MORTAR BED. The concrete foundation prepared as specified above shall be cleaned and swept and shall be thoroly dampened immediately in advance of the spreading of the cushion course. Upon the surface of the foundation thus prepared shall be spread a layer of mortar not exceeding ½ in in thickness and made of one part Portland cement of the character specified for use in the foundation and three parts of sand. Only sufficient water shall be added to this mixture to insure a proper setting of the cement, the intention being to produce a granular mixture which may be raked or struck by templets to the desired grade. The mortar shall be thoroly mixed and shall be spread in place upon the foundation by means of templates immediately in advance of the laying of the blocks to such a thickness that when the blocks are set and properly bedded in the mortar, their tops shall conform accurately to the finished grade of the roadway.

"SAND. Upon the concrete foundation shall be spread a cushion of sand 1 in in thickness. The sand cushion shall be struck by templates to a surface parallel to the grade and contour of the finished pavement in such a manner that when the blocks are set and thoroly bedded in the sand the tops shall conform accurately to the finished grade of the pavement. The sand used in this cushion shall all pass the ¼-in screen and must contain between 10 and 25% of loam or clay.

"Laying the Blocks. Upon the bed thus prepared the blocks shall be carefully set with the fiber of the wood vertical, in straight parallel courses, leaving a space next to the curb 1 in in width for the expansion joint. They shall be placed closely together on the prepared cushion and no joint shall be more than ⅛ inch in width. Nothing but whole blocks shall be used except in starting a course, or in such other cases as the purchaser may direct; and in no case shall the lap be less than 2 in. Closures shall be carefully cut and trimmed by experienced men. The portions of the block used for the closures must be free from checks or other fractures and the cut end must have a surface perpendicular to the top of the block and cut to the proper angle so as to give a close, tight joint. The angle of the course with the curb shall be determined by the purchaser. After the blocks are placed they shall be rolled parallel and diagonal to the curb by a tandem roller weighing between 4 and 7 tons, until the surface becomes smooth and is brought truly to the grade and contour of the finished pavement. In case of a mortar bed the rolling shall be completed before the mortar bed has set. All mortar that has set before the blocks are in place and rolled shall be discarded and replaced by fresh mortar.

"Filler. After the rolling is completed the joints between the blocks shall be filled with either a pitch or asphalt filler as specified hereafter. The filler shall be brought to the proper temperature and poured into the joints, and any filler on the surface of the pavement must be spread as thin as possible by means of squeegees. The receptacle in which the filler is heated shall be equipped with suitable thermometers. After the joints are filled as described, the surface shall be completely covered by a thin coat of coarse, clean, dry sand, and a similar sand shall be spread over the pavement, if required by the Engineer, before the acceptance of the pavement.

"PITCH FILLER. The filler shall be a straight run residue obtained from the distillation of coal tar, and shall comply with the following requirements:

1. The melting point shall not be lower than 60° C (140° F), nor higher than 66° C (150° F).
2. It shall contain between 22 and 37% of free carbon insoluble in hot chloroform and benzol.
3. The specific gravity at 25° C (77° F) shall not be less than 1.24 nor more than 1.32.
4. The specific gravity of the distillate up to 355° C shall not be less than 1.07 at 38° C (100° F), compared with water at 15.5° C (60° F).

The pitch shall be heated to a temperature not exceeding 163° C (325° F), and shall be poured at a temperature between 121° and 149° C (250° and 300° F).

"Asphalt Filler. The filler shall be an asphalt filler and shall comply with the following:

1. It shall contain at least 98% of bitumen soluble in carbon disulphide.

2. It shall have a penetration within the following limits: When tested for 1 min at 0° C (32° F) under 200 g, 10 to 20; when tested at 25° C (77° F), for 5 sec under 100 g, 30 to 50; when tested at 46° C (115° F), for 5 sec under 50 g, 150 to 300.

3. It shall show a ductility of at least 30 cm when tested at 25° C (77° F).

4. When 50 g are heated in an open tin to a temperature of 163° C (325° F), for 5 hr, the loss shall not exceed 1% and the penetration at 25° C (77° F) of the residue left after such heating must not be less than two-thirds of the penetration of the original asphalt cement before such heating when tested at 25° C (77° F).

"Sand Filler. After the rolling is completed the joints between the blocks shall be filled by sweeping dry clean sand into them, after which the surface shall be covered to a depth of about 1/2 in with fine sand. This sand is to be left upon the pavement for such a time as may be directed by the City, after which it shall be swept up and taken away by the Contractor.

"Blocks on Grades. When the blocks are laid on streets having grades of 3% or over, it is desirable that the blocks be spaced by laying creosoted wood lath, about 5/16 in thick, between each course. The space above the laths shall then be filled with heated crushed stone, containing no dust, and bituminous filler as specified above. The bituminous filler shall first be poured into the bottom of the joint, care being taken to get none on the surface of the pavement. The crushed stone shall then be swept into the joint and the space around the stone filled with a bituminous filler to the top of the joint. It is essential in open joint pavement to drive together the blocks every four rows to prevent tipping of the individual blocks."

11. Construction Cost Data

Minneapolis. The detailed cost of wood block pavements, where the work has been done by city employees for many years, not including foundation, is as follows:

1 superintendent, part time	$1.00
1 timekeeper, part time	0.50
1 foreman	4.50
1 team	5.00
1 roller man	4.00
1 watchman	2.50
2 tar men	5.25
1 inspector	2.50
1 sweeper	2.50
3 men throwing to pavers	7.50
6 wheelers	15.00
4 block layers	12.00
2 trimmers	6.00
1 line man	2.50
1 bed man	3.50
4 sand spreaders	10.00
1 concrete sweeper	2.50
32	$86.75

This organization will lay on an average of 1500 sq yd per day, under good conditions. Average, $0.0578 per sq yd. The entire cost of laying the pavement, not including foundation, is as follows:

Hauling blocks	$0.066
Laying blocks	0.058
Miscellaneous, clearing street, moving on and off of tools	0.024
Cushion sand $0.75 per cu yd	0.024
Pitch, $12.00 per ton f. o. b	0.055
Creosoted blocks, $1.40 per sq yd, f.o.b	1.400
Total	$1.627

The blocks used were southern yellow pine 4 in deep, with a treatment of 16 lb per cu ft.

New York City. The cost of laying 800 sq yd follows:

1 foreman	$4.00	
1 bedmaker	3.20	
2 men on striking board	6.40	
10 laborers making and spreading mortar bed	17.50	
4 pavers, one cutting in	12.80	
16 laborers handling blocks, etc	28.00	
1 roller man	5.00	
1 helper	2.50	
1 laborer cleaning up	1.75	$81.15
The cost of joint filling follows:		
1 laborer tending kettle	2.00	
2 laborers carrying pitch	4.00	
2 laborers pouring	4.00	
4 laborers squeegeeing	8.00	18.00
Total labor		$99.15

Cost of labor per yard	$0.124
Cost of mortar bed per sq yd	0.090
Cost of pitch per sq yd	0.075
Cost of 4-in block, 20-lb treatment per sq yd	2.000
Total	$2.289 per sq yd

Wenatchee, Wash. (36). Cost details of laying 27 595 sq yd of wood block pavement on Wenatchee Ave. in 1913. Construction: 4 in, 16 lb creosoted Douglas fir blocks, joints filled with asphalt; 1 in sand cushion; 5 in 1 : 3 : 6 cement-concrete foundation. Common labor, $2.50 per 8-hr day; block layers, $10.00 per 8-hr day. Roller rent $3.50 per day. Wood blocks, $1.75 per sq yd, f.o.b. Wenatchee plus $1.10 per thousand for unloading and hauling.

Cost of Materials

		Amount Used per Sq Yd	Cost per Sq Yd	
Foundation	Gravel, $1.30 per cu yd	0.0973 cu yd	$0.1263	
	Sand, $1.00 per cu yd	0.0486 cu yd	0.0486	
	Cement, $2.10 per bbl	0.125 bbl	0.2625	
	Water	....	0.0100	
	Mixer (interest and depreciation)	....	0.0152	
Cushion	Sand, $1.00 per cu yd	0.0278 sq yd	0.0278	
Blocks	Blocks, $1.794 per sq yd	42.25 blocks	1.7940	
	Asphalt filler, $37.75 per ton	0.0031	0.1153	
Total cost of materials per sq yd				$2.3997

Cost of Labor

		Cost per Sq Yd	
Foundation	Mixing	$0.0523	
	Placing	0.0205	
Cushion		0.0141	
Blocks	Laying	0.0160	
	Helping	0.0435	
	Rolling	0.0159	
	Filling	0.0599	
Total cost of labor per sq yd			$0.2232
Total cost of pavement and foundation per sq yd			$2.62

England. Swedish deal blocks laid on concrete with a cushion coat of asphalt cost $3.08 per sq yd and had an average life of 7 years, and cost $0.209 annually for repairs. Creosoted blocks, lime joints, cost $2.95 per sq yd, with an average life of 8 years, and cost $0.204 per year for repairs. Creosoted blocks with asphalt mastic joints cost $3.55 per yd, with an average life of 8 years, and cost $0.24 per year for repairs. Pitch-pine blocks cost $2.91 per sq yd, with cement joints, with a life of

9 years, and were maintained at an expense of $0.088 per sq yd per year for repairs. The life of these foreign pavements is estimated for the traffic standard of 750 tons per yard of width per day.

Table I.—Character and Cost of Wood Block Pavements in 1915 in Several Cities

From *Engineering and Contracting*, April 5, 1916

City	Sq Yd	Price* per Sq Yd	Guarantee Years	Kind of Filler	Concrete Foundation	
					Thickness In	Proportions
Boston, Mass.	12412	$3.25	5	Sand	6	1 : 3 : 7
New Haven, Conn.	41623	3.37	5	Sand	6	1 : 3 : 6
Providence, R. I	39412	3.36	5	Sand	6	1 : 3 : 6
Borough of Manhattan, New York City	6024	3.12	5	Asphalt	6	1 : 3 : 6
Jersey City, N.J.	7271	2.46†	5	Sand	5	1 : 3 : 5
Cumberland, Md.	5616	2.89	5	Cement grout	6	1 : 3 : 6
Akron, Ohio	3500	2.05†	2	Tar	4	1 : 2½ : 5
Toledo, Ohio	38406	3.19†	5	Sand	7	1 : 3½ : 6
Chicago, Ill.	68140	3.22†	5	Pitch	6	1 : 3 : 6
Gary, Ind.	3116	2.75†	5	Asphalt	6	1 : 3 : 5
Detroit, Mich.	253067	2.43	0	Tar	6	1 : 3 : 6
Milwaukee, Wis.	17584	2.50†	0	Pitch	6	1 : 3 : 6
Minneapolis, Minn.	117562	2.38	..	Pitch	5	1 : 3 : 6
Cedar Rapids, Iowa	3115	2.74†	5	Asphalt	6	1 : 3 : 5
Sioux Falls, S. D.	2225	2.82	5	Pitch	6	1 : 2½ : 5
Petersburg, Va.	13000	2.62†	5	Sand	5	1 : 3 : 6
Nashville, Tenn	27639	2.64	5	Pitch	5½	1 : 3 : 6
New Orleans, La.	47370	3.25	8	Tar	6	1 : 3 : 5

* Price covers pavement, foundation and subgrade.
† Does not include shaping subgrade.

MAINTENANCE

12. Bleeding

Two of the greatest objections to treated wood block pavement are its liability to bleed when first laid and its occasional bulging due to the expansion of the blocks caused by the absorption of water in wet weather. In New York City there has been some trouble on this account, but not to such an extent as in the West. One reason for the blocks in New York not bleeding as much as those in the West is probably because of the fact that the joint filling in New York has generally been sand, while in the early pavements of Chicago it was pitch or some other bituminous material. By this term is meant the exudation of the preservative during warm weather soon after the pavement is laid. This occurs in different degrees in different cities under different conditions. In Cincinnati, Ohio, and Chicago there has been some trouble on this account, and many have been the complaints of the property owners because of this, as it makes the pavement very sticky, and is therefore tracked into residences and business houses. This bleeding occurred slightly with the creo-resinate process,

but in an entirely different way. The exudations then were altogether of rosin, which soon cooled and formed a hard, glassy substance, which was exceedingly slippery for horses. That, however, was soon crushed and worn out by heavy traffic. On the first pavement laid in Brooklyn, N. Y., there were quite a number of complaints on account of slipperiness soon after the pavement was laid. This was on a residential street, where the traffic was light, but even then the complaints soon ceased. One of the problems of the wood block manufacturer is to overcome this tendency of the blocks to bleed. Just what causes it or accelerates it is uncertain. It is probable, however, that the greater the treatment given the blocks the more they will bleed, no matter what the preservative. The advocates of the light oil claim that there will be very little bleeding with that material and that the trouble is caused almost entirely by the mixture of the tar with the creosote oil. Others think that the bleeding is caused almost entirely by the expansion of the blocks, the pressure forcing the preservative to the surface. The Chicago specification requires oil to be of 1.08 to 1.12 specific gravity, and provides that it shall be an absolute distillate of coal tar. This means that no filtered tar can be mixed with the oil itself. Since the use of this oil the trouble from bleeding has almost entirely ceased. It occurs during the first warm days of spring. On a street that is partially shaded the bleeding often occurs very freely on one side and not at all on the other. This would seem to refute the argument of those who claim that bleeding is caused by the expansion of the blocks. This exudation is not entirely bad, as it brings the preservative to the surface and so renders the top of the block absolutely watertight. When it occurs to a great extent it can be overcome by sprinkling the surface of the pavement with sand, which is scraped off after the preservative has been absorbed. Some trouble occurs on this account in the European cities, but not much, as the treatment of the blocks is so light.

Howell (26b) states that: "The bleeding was extremely noticeable on several warm days when the thermometer ranged from 32° to 36° C (90° to 97° F) in the shade, and possibly 46° to 49° C (115° to 120° F) on the pavement, but by causing the blocks to be covered with a thin coating of sand, no unpleasant conditions followed. During the summer and fall the pavement was sprinkled quite frequently. Early in the fall a thick coating or crust formed on the top of the blocks, caused by the oozing out of the preservative and its coming in contact with the sand. The contractor scraped this off and removed it from one street on several occasions. This coat did not stick to shoe leather to any appreciable extent, and did not cause any unfavorable comment from storekeepers in regard to being tracked into buildings and soiling the floors, as was the case with the wood block pavement on Market St., Philadelphia, a few years ago."

Teesdale (41a) has described, as follows, an investigation of bleeding which was intended to include those factors entering into the selection of material and its treatment at the plant that might have an influence on bleeding. The investigation covered, (1) Species and rate of growth. (2) Moisture condition of the wood when treated. Green and air-dried wood was tested. (3) Character of preservative used. A distillate creosote oil and a mixture of this with tar, the latter intended to be representative of the grade of paving oil in general use, were tested. (4) Manipulative methods employed in treatment, especially the use of steam and vacuum treatment and preliminary air pressures. In addition, tests were made to determine the effect of varying the absorption of preservative, and of subjecting treated blocks to external pressure, a condition sometimes obtained in a street when the expansion trouble exists.

"MATERIALS USED. Wood: Green long-leaf pine and thoroly air-dried long-leaf pine, rapid growth loblolly pine, and eastern hemlock blocks, 4 in by 8 in by 4 in were used in the work. The long-leaf pine was regular paving block stock; the other material was sawed from ties. Preservatives: Two preservatives were used in the

investigation of bleeding. One was coal tar creosote with a specific gravity of 1.07 at 60° C (140° F). The other was a 50% mixture of this creosote with a by-product coke-oven tar having a specific gravity of 1.17 at 60° C (140° F), and containing about 6% free carbon. This mixture was believed to be comparable to much of the paving oil used for treating blocks.

"METHOD OF MAKING BLEEDING TESTS. After treatment, the blocks were placed in an oven in tin boxes, and subjected to a constant temperature of 49° C (120° F), until the oil ceased to bleed from them. Blotting paper was used to absorb the oil as it came from the blocks. Weights were taken at suitable intervals, corrections being made for losses by volatilization. In the data presented, an average of two blocks was taken in each case.

"The results indicate that a preliminary vacuum especially is a very important factor in treating air-dry paving blocks if bleeding is to be reduced. Steaming, when used without a vacuum period, was not very efficient in reducing bleeding when creosote was used. With the tar and creosote mixture, however, the reduction in bleeding was very marked. Steaming evidently has a much greater effect on the tar and creosote mixture than on the creosote. With either green material, and with either the creosote or the tar and creosote mixture, bleeding was greatly reduced when both steam and vacuum treatments were applied. It will be noted that the loblolly pine bled very much more than the long-leaf pine when no preliminary vacuum was used. When preliminary vacuum was used, the absorption could not be controlled and 40 lb per cu ft were absorbed. While the percent of bleeding was reduced the total amount of bleeding was, therefore, still very large. Bleeding was materially increased when absorption was increased, especially when more than 16 lb per cu ft were injected, or when the tar and creosote mixture was used. The effect of outside pressure, intended to show the effect of the expansion of blocks in the street on bleeding, did not appear to have much influence on bleeding. The blocks in this case were compressed in an iron clamp until the wood was crushed. This extreme condition would not be reached in the street. Nevertheless, bleeding was not greatly increased. When no preliminary vacuum or steam treatments were used, the blocks treated with tar mixtures in most cases bled considerably more than those treated with creosote; this was true regardless of species. Steaming blocks prior to treatment appeared to have a very marked retarding influence when tar was used. The tar appeared to dry in the outer pores of the wood, forming a mat that retarded bleeding. The use of a final steam bath did not influence the bleeding materially, but removed carbon from the surface and greatly improved the appearance of blocks treated with the tar mixture. All of the results seem to indicate that bleeding is caused to a large extent by the expansion of air in the wood cells. Other contributing causes which no doubt aggravate bleeding are expansion of the preservative in the wood, external pressure exerted upon the blocks, excessive absorption of preservative by some of the blocks, and the use of rapid growth woods. Sapwood is also a factor, largely because of the excessive absorption of oil that it takes."

Weiss (7) states, that "From observations and tests made by the author it is believed that bleeding can be eliminated if (1) only slow-grown wood is used for the blocks; (2) if green timber or steamed seasoned timber is used; (3) if a strong preliminary and final vacuum is drawn before and after the oil is injected; (4) if when tar is used the blocks are steamed slightly after the oil is injected; (5) if the penetrations are made complete; (6) if impregnations no greater than 16 lb per cu ft are given; (7) if straight coal tar creosote or coal tar creosote containing only small amounts of carbon-free tar is injected; (8) if the blocks are not laid too close together; (9) if excess tar or pitch is not poured between the joints. All of these requirements can be easily met without added cost."

It would seem that, without question, with a few years more experience it will be easy to determine what is the best method of reducing bleeding. The conclusions of Weiss seem logical, and, as he states, his conditions can be complied with without extra cost.

13. Swelling

The bulging of wood pavements on account of the expansion of the blocks has caused a great deal of trouble and has retarded to quite an

extent the use of this material in pavements. Wood of itself is a very unstable material, changing a great deal according to its moisture content, and it is necessary to have the blocks so treated that they will not unduly expand or shrink according to climatic changes. When the wood pavements were laid in Brooklyn, N. Y., in 1902 to 1904, inclusive, with the creo-resinate process, provision was made for a water absorption of not more than 3%, without any expansion joint whatever, and on the streets where city inspection prevailed no trouble from expanding or bulging has occurred.

In Germany, in order to overcome the swelling or bulging of the pavement in wet weather, in some cities the surface of the pavement is kept moist and the surface tarred so that the water cannot penetrate into the blocks. The wood pavements of Berlin in summer, when water is plentiful, are watered three times a day.

In Paris much trouble has been caused by this bulging. This is not strange when it is considered that up to 1913 the blocks contained only 3 lb of oil per cu ft. Tur (43), the Engineer in charge of wood pavements in Paris, in a discussion on bulging, says:

"In practice it is impossible to foresee the circumstances under which any road will absorb water and will expand. The phenomenon depends on the quality of the wood, the quantity of water with which it was impregnated at the moment of laying and the atmospheric conditions prevalent from that time on. Thrusts are usually exerted perpendicularly to the axis of the road. They usually displace the sidewalk, curbs, and quite often the tracks of the tramways. Sometimes, too, they manifest themselves in a longitudinal direction by more or less extended upliftings of the entire pavement. The displacement of the curbs and the parts near the flagging never cause any noteworthy trouble, nor do the partial liftings of the wood pavement. The danger of damage from this cause can be reduced by sprinkling the blocks thoroly before laying them. In order to facilitate repairing of the sidewalks, a joint filled with sand is made, as we have already said, along the curbs. As for the liftings, which occur more rarely, they are easily removed by extracting one or two rows of blocks. Unfortunately the system which will render wood pavements entirely harmless has yet to be found. The effect of sprinkling the blocks before laying can never be other than temporary, and it is often ineffective."

Experience in the United States.

Roberts (34) has given the following facts relative to a striking example of expansion in wood pavement which occured in 1911 in the City of Longview, Texas. The street paved had a roadway of 70 ft, and contained 16 000 sq yd. The pavement was laid with a great deal of care on a concrete foundation, with a 1-in sand cushion and a 2-in expansion joint on each side of the roadway. The summer of 1913 was exceedingly hot and dry, there being no rain for 65 days prior to Sept. 7, when a severe rain storm set in, which continued for 8 days, during which time 9.37 in of rain fell. On the second day of the rain the blocks began to swell, so that street-car traffic was stopped and ordinary street traffic seriously hampered. The breaking up of the pavement extended transversely and longitudinally along the street, the failure across the roadway being the greater. The expansion across the roadway was measured and was found to be about 8¼ in. On Sept. 14, when the storm was nearly over, three sample blocks were taken and weighed, the mean weight being 56.9 lb per cu ft. On Oct. 6, after 23 days' drying at an even temperature of 21° C (70° F), these three sample blocks were again weighed, on the same scales, and showed an average weight of 47.4 lb per cu ft. From over 9 in of rain these blocks had absorbed an average of 9½ lb of water per cu ft. After drying 14 days more a further loss of 4.3 lb was shown, the mean weight then being 43.1 lb per cu ft, a total loss of 13.8 lb per cu ft after 37 days' drying.

The causes of the phenomena, in the order of their importance, were decided to be: (1) Extreme weather conditions of 65 days' drought followed by 8 days of rain in which 9.37 in fell; (2) the removal of the protective sand covering too soon after the completion of the pavement; (3) the use of extremely fine sand for the cushion;

(4) laying the blocks too tight; (5) neglect to sprinkle and oil at intervals; (6) pavement of this type too wide (70 ft) for the traffic that it has to carry.

Green (22), reporting further on this, states that the timber was treated with 20 lb per cu ft of creosote oil having a specific gravity of 1.05. The timber itself was almost entirely short-leaf yellow pine, weighing about 32 lb per cu ft when seasoned. The blocks were laid close, but were not tightly driven as a rule. The joints between the blocks and rows were filled with sand. When the blocks were examined it was found that nearly 50% of the original oil with which they were treated had evaporated.

Howell (26a) states that the Newark specifications provide for expansion as follows: "(1) By providing for expansion joints along the curbs, 1½ in wide, to be filled with a suitable bituminous filler capable of passing a good penetration test; (2) by laying the blocks comparatively loose in the pavement in order not to have any tight joints, sand being carefully broomed into the joints; (3) by soaking all of the blocks in 40 or 50 barrels, used as tubs, in which the blocks were required to be submerged in water for 10 min before laying."

The theory of soaking the blocks in water is undoubtedly that they will expand, so that after being laid in the pavement any further expansion will not cause bulging. If this treatment should be satisfactory it would be a simple matter to provide for it, but it would hardly seem that a block treated with 18 lb of creosote oil would swell to any appreciable extent by an immersion of 10 min in water. Howell stated that up to Dec., 1914, there had been no real trouble on account of bulging, except along the railroad tracks where the water got under the blocks.

Teesdale (41a) states regarding experiments on swelling, that "The first series was made to determine the effect on swelling of various percentages of tar, and also of free carbon in mixtures of tar and creosote. The second series was made to determine the influence of varying the method of treatment on swelling. All of the blocks in the first series, and one-half of those in the second series, were soaked in water after treatment until they ceased to expand. In order to correlate these results more closely with service conditions, the remainder of the blocks in the second series were, therefore, placed on the sand cushion and sprinkled with water twice each day until they ceased to change in size. Two sticks of thoroly air-dried long-leaf pine were cut into blocks 4 by 4 by 8 in. After the blocks were cut they were piled in the laboratory for several months before treatment to insure a uniform moisture condition. For each treatment given one block was used from each stick, thereby giving two blocks treated with the same preservative.

"The following preservatives were used in this experiment:

1. A coal tar creosote having a specific gravity of 1.07 at 60° C (140° F). The same as used in the bleeding test.

2. A by-product coke-oven tar containing 6% of free carbon and having a specific gravity of 1.184 at 60° C (140° F). The same as used in the bleeding tests.

3. A by-product coke-oven tar containing 16% of free carbon and having a specific gravity of 1.232 at 60° C (140° F).

4. A gas-house tar containing 30% of free carbon and having a specific gravity of 1.273 at 60° C (140° F)."

After detailing the methods of conducting his work, in the discussion of his results he says: "It is evident that the rate of swelling was considerably retarded in the treated blocks, and that the maximum swelling was not as great as that obtained on untreated blocks. The maximum swelling of untreated wood was reached in 40 days, while from 5 to 10 months were required to reach a maximum in the treated blocks. Blocks treated with mixtures of carbon-free tar and creosote showed a slower rate of swelling as the percent of tar in the mixture increased; this was not marked, however, until from 50 to 75% of tar was used in the mixture. In most cases the maximum swelling of blocks treated with tar mixtures was from 10 to 25% less than in those treated with creosote. There was also considerable difference in the amount of swelling obtained in blocks treated with different kinds of tars. Air-dry long-leaf pine, green long-leaf pine, and air-dry rapid growth loblolly pine were used. All of the blocks were cut from the heart-wood. The seasoned material was obtained in an air-dry condition, and after being cut into blocks, was seasoned in the wood preservation laboratory for several months before being treated. Creosote, and a mixture of 50% creosote and 50% by-product tar were used. These oils were the same as those used in the bleeding tests. The following treatments were made with each preservative on

seasoned long-leaf pine, using 10 lb and 16 lb per cu ft absorptions in each case: (1) No preliminary or final vacuum; (2) preliminary but no final vacuum; (3) final but no preliminary vacuum.

"The results are not very consistent, but they indicate that the air-seasoned long-leaf pine blocks treated with either oil did not swell as much if given a preliminary vacuum, as when no vacuum period or final vacuum was given. Also that blocks treated with the creosote and tar mixture swelled less than those treated with creosote, unless a preliminary vacuum was used. No difference in swelling was indicated between the 10-lb and the 16-lb treatment except that the results obtained from the latter were more consistent, due probably to more uniform penetration There is no indication that increasing absorption decreases swelling in either case. In general, the blocks treated with the creosote and tar mixture swelled less than those treated with creosote alone. Similar tests were made on green blocks. Practically no swelling was noted. Measurements were made on a few of the blocks placed on the sand cushion to determine the difference in swelling between the top and bottom of the blocks. In all of the previous tests the tacks were placed 1 in from the bottom face. In this test, additional tacks were placed 1 in from the top. The curves, as well as the appearance of the blocks themselves, show very strikingly the greater amount of swelling that occurred in the bottom of the blocks. This in some cases is very probably a cause of buckling, especially where the pavement has considerable crown, due to the upward force liable to be exerted if the bottom of each block expands more than the top. This is liable to occur if water penetrates the filler and reaches the sand cushion."

Among his conclusions he gives: "Increasing the absorption of oil above 10 lb per cu ft had but little influence in reducing swelling. No swelling was obtained in blocks treated in the green condition. It was possible to obtain the desired absorption by increasing the time and pressure of the treatment as the percentage of tar was increased. The penetration of preservative was more uneven as the percentage of the tar in the mixture was increased. The decrease in swelling obtained by varying methods of treatment, or by using tar mixtures, does not seem to be sufficient in itself to prevent expansion in street pavements. The use of green material was the most effective of the methods tested. These tests seem to indicate that long-leaf pine paving should be treated in the green condition after being well steamed. All blocks, even if thoroly air-seasoned, should be well steamed. While it is true that a preliminary and final vacuum greatly retarded bleeding and to some extent the swelling of air-seasoned wood, a preliminary vacuum will tend to make the absorption of oil too rapid during treatment, resulting in uneven penetration. A steaming period is, therefore, advisable to render the absorption less rapid and allow a longer and more intense pressure period to be applied. Furthermore, if seasoned blocks are steamed, they will take up moisture and expand and should be less liable to give trouble from swelling after laying in the street. For these reasons it would be preferable to treat green material when it is possible to obtain it."

He also says that if the blocks cannot be laid soon after treatment, they should be covered and perhaps wet down occasionally to prevent them from drying out. Also, that absorptions of over 16 lb per cu ft hardly seem necessary; that the reason why some pavements bleed while others do not may be often traced to the method used in treatment; that the tests do not indicate that the use of tar mixtures will prevent swelling, altho they tend to retard it; that the tests indicate that increasing the absorption of oil above 10 lb per cu ft does not tend to appreciably decrease swelling; that in drawing up specifications for treating blocks the waterproofing effect of the oil should not receive much consideration, the main points to be considered being to have sufficient oil of a good grade to obtain a thoro penetration in order to avoid decay, and to specify a method of treatment that will not cause the blocks to bleed. The tests also indicate that swelling should be controlled principally by having the blocks in the green condition when laid in the street, and by taking special care with the filler and method of laying so that water will not penetrate to the bottom of the blocks.

Weiss (7), in speaking of expansion, says: "It is wasted effort to try and make the blocks non-expansive, for no matter how much oil is forced into them they will absorb more or less water in time. Furthermore, the oil and wood will expand due to rise in temperature. Best practice, therefore, is to keep the absorption of water to a minimum by proper treatment and to allow for expansion by carefully laying the pavement as described above."

14. Slipperiness

One of the great objections to wood pavement is its slipperiness. This is a valid objection, as creosoted wood pavement is probably more slippery than any other kind of pavement. This, however, depends a great deal upon conditions, as if the pavement be dry, there is no trouble whatever, but when somewhat moist, especially if not clean, there is apt to be trouble on account of lack of foothold for horses. So that, in considering this material for a street, special care must be given to a study of conditions, the rate of grade, and the amount and character of traffic. It may be said that in the west, especially at Minneapolis, Minn., and Great Falls, Mont., very little trouble has been experienced on account of slipperiness. This may be due to the natural dryness of the atmosphere. In New York City, however, slipperiness on wood pavements is very observable. In such a climate it is advisable not to lay wood on grades of more than 2% without some special treatment. This general rule, however, can be modified if the street is one that does not have a large amount of continuous traffic, or if the traffic can be easily diverted in case of emergency to adjacent streets. On such a street the few days in the year when a wood pavement would be slippery would not be so important, but where a street is used constantly by heavy traffic every day despite the weather, it is extremely necessary that every care should be taken to prevent slipperiness. There are several ways, however, of mitigating this nuisance of slipperiness. In foreign countries the practice of sprinkling the pavements with sand is much more general than in the United States. The wood pavements abroad, too, are softer, so that sand or gravel spread upon the pavement is driven into the blocks by the traffic to a much greater extent than would be the case with the yellow pine blocks of America. The officials of American cities have not generally taken up the plan of sanding the streets when slippery. If this were done systematically much of the trouble which occurs from slipperiness would be avoided, without much expense.

Fig. 3

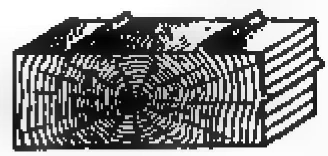
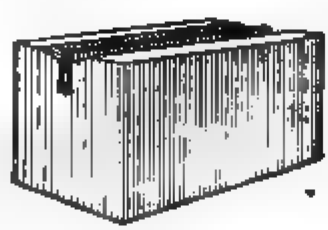


Fig. 4

Fig. 5



Size of Block
4 by 5 by 12 in

Fig. 6

Kreolite. A form of wood pavement that has recently come into use in this country is known as Kreolite. The blocks are the same as those for ordinary wood pavement, excepting that they have lugs on one side and one end about ¼ in long. The object of the lugs is to separate the courses so that the pavement will not be so slippery, and also that there may be an expansion joint between each course of blocks, the idea being that the lugs will crush and so take up the natural expansion of the block itself, thus preventing bulging in the pavement. It is also claimed that, as treatment of

over 12 lb per cu ft is mainly to prevent bulging of the pavement, with this system a much less amount of preservative can be used, thus cheapening the pavement in that respect. This pavement has been used to quite an extent on bridges and in certain cities of the central west. Fig. 3 shows a portion of this pavement laid, and Fig. 4 one of the blocks. A device which has been gotten up to prevent slipping consists of grooving the upper face of the block and inserting in the groove a steel grid so that its top will come just above the surface of the block itself. When this pavement is laid on grades which are somewhat too heavy for the ordinary wood block, every third course is laid with the gridded blocks; but if the grade is very steep, every other course is laid with the grids. The extra cost of this pavement is about 65 cents per sq yd when one course in three is used with the grids, and $1 per sq yd when every other course is gridded. The blocks are treated in the usual way, the grids being simply to afford a foothold for the horses. Fig. 5 shows a portion of a pavement laid with three-and-one courses, and Fig. 6 a block with the grid inserted.

15. Maintenance Cost Data

Observations made by the Bureau of Highways, Borough of Manhattan, New York City, show a wear on the granite pavement on the approach to the Brooklyn Bridge of 0.0490 in per 100 tons, but for the wood pavement on the Queensboro Bridge a wear of 0.0203 in per 100 tons; on the Washington Bridge, 0.0231; on the Metropolitan Ave. Bridge, 0.0231; on the Meeker Ave. Bridge, 0.0300. On 20 London streets paved with wood the wear was reported as 0.0615 in per 100 tons, and on the Minneapolis, Minn., experimental pavements, previously referred to, 0.0222. It will be noticed that the wear on the wood pavement of this country is very uniform, and that it is about one-half the wear on the granite pavement, and one-third the wear on the London pavements. This is not surprising for the London pavements, as the wood there is much softer and wears more rapidly than American wood. It is, however, somewhat surprising that the wood should wear less than the granite.

Minneapolis, Minn. (19d). "The following is the cost in cents per square yard per year for repairs of creosoted wood block pavements in Minneapolis for the various years, and also shows the total yardage in place on Jan. 1st of each year:

Year	Total Sq Yd	Maintenance per Sq Yd in Cents
1907	210 464	0.012
1908	312 815	0.085
1909	457 583	0.052
1910	600 922	0.064
1911	757 472	0.294
1912	928 726	0.162
1913	1 060 688	0.193
1914	1 195 932	0.254
1915	1 381 605	0.239
1916	1 516 819	0.054

London. The cost of repairs varies very much with the method of making them. A contract was made to keep Piccadilly and part of Kings Road in repair for 15 years for 3s. (73 cents) per yd per year, when the Engineer estimated that its cost would not be more than 2s (49 cents). The annual cost per square yard for a plain deal, spread over 15 years, ran 1s. 8¾d. (82 cents), with a traffic of 279 tons, to 3s. 2d. (77 cents) for improved pitch-pine, with a traffic of 558 tons per yd per day. These figures were made in 1884. In 1893 a portion of the Euston Road was paved with wood;

63 ft with yellow deal, 62 with Karri, 49 with yellow deal, and 63 with Jarrah. After 3 years' time the wear was found to be 1/4 in on Jarrah and Karri, and 1 3/8 in on the deal. From observations taken, the traffic was found to be 575 544 tons per yd of width per annum. On another portion of the same road the wear was 1/5 in per annum with a traffic of 411 318 tons. Tottenham Court Road, which was paved with Jarrah blocks, showed only 1/4 in of wear after 3 years, with greater traffic than Euston Road, and on the Westminster Bridge Road, after nearly 7 years of wear, the Jarrah blocks had worn from 1 1/16 to 1 1/8 in, with a traffic of from 233 to 334 tons per ft of roadway in 12 hr.

Paris, in 1911, spent $902 989 for the maintenance of her wood pavements, which was nearly 33 cents per sq yd over the entire surface. This, however, provided for renewals as well as repairs. If the cost of repairs only were considered it would amount to 26 cents per sq yd over the entire surface maintained. Some idea can be had of the traffic of the Paris streets when it is known that the average life of wood in that city is 8 years, and, on the Arc de Champs Elysées, from 6 to 7 years only.

Petrograd. The wood blocks have a durability on an average of 3 years. It is estimated that the cement layer on the concrete will be renewed every 6 years, so that the annual cost of a wood pavement on concrete foundation would be 36 cents per sq yd. While the wooden foundation does not wear out, it does rot out, as its life is given as 6 years, so that the annual cost of a wood pavement on a wooden foundation is 46 cents per sq yd.

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SECTION 19

STONE BLOCK PAVEMENTS

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GENERAL DATA

1. Historical Development

As stone was the most durable natural material that was generally known to the ancients it is not surprising that the first pavements were laid of that material. Just when the first pavements were laid is uncertain, but it is reported that stone roads were built between 1000 and 2000 B. C. The streets of Rome were said to have been paved in the 4th or 5th century after the founding of the city, while the first pavements in Paris were laid about 1184, when the city had a population of about 200 000. The Strand, London, was ordered paved by an Act of Parliament in the 14th century, and the streets outside of the city in the 16th century, altho it is stated that the first regular pavements were laid in 1533, when the city had a population of 150 000. It might seem strange in these days, when a modern city of 5000 people thinks it is not progressive unless it has street pavements, that cities should attain the size of Paris and London at the time mentioned before having improved streets, but in explanation it must be remembered that in those days streets were not used for vehicular traffic, as merchandise was generally carried on horseback and people were taken about the cities in chairs. As late as 100 years after the reign of Queen Elizabeth pack-trains were regularly used for commerce in England.

Character of Blocks. The early pavements were constructed of large, irregular stones, without much regard for smooth surfaces, the idea being mainly to keep what traffic did use the streets and roads out of the mud

and dust. Figs. 1 and 2 show the character of stone used in a road built by the Romans on the Septimer. While built of irregular stones, these roads were very substantial, often being laid in mortar and being really solid masonry constructions.

The streets of Pompeii, disclosed by recent excavations, show the class of stone used in the streets of that city, which incidentally are probably the oldest pavements that have been seen by people of the present day. These stones, comprising several square feet in area, were undoubtedly of lava, which would soon become smooth even under foot wear. They were laid with fairly close joints, but their condition indicates that they were not laid with regard to vehicular traffic. The roadway was narrow, and at street crossings large circular stones were placed at such distances apart that they could easily be used by pedestrians, but which would practically block vehicular traffic. In some instances the streets were so narrow that only one stepping stone was required, but on other streets more were required.

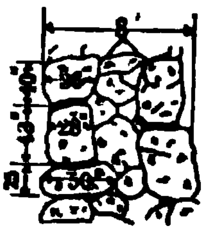

Fig. 1

As the needs of traffic and civilization increased the demand arose for improved streets, and consequently a better class of pavement, which

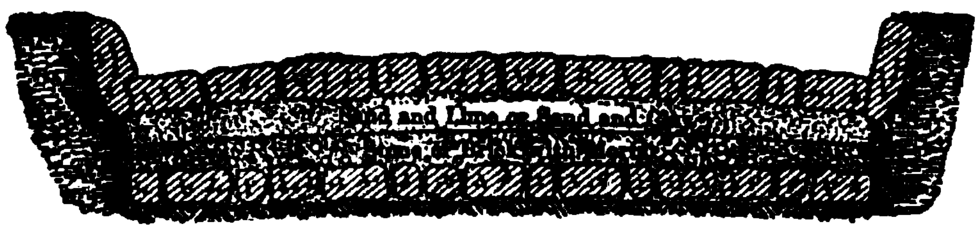

Fig. 2

required better blocks. Even after the blocks began to be improved they were of large size, especially in the Italian cities. Fig. 3 shows a typical street in Catania, Italy. The blocks of which the pavement is laid are of hard lava, 16 by 20 in in size and 8 in thick. In Palermo, Sicily, blocks were used to within quite recent date 18 by 24 in on top and from 8 to 10 in deep, while in Triest, Austria, they were from 24 to 60 in in length, 12 to 18 in in width and 6 to 10 in deep, and in Milan, Italy, they were also very large. When the Forum Trajanum was cleaned by the French in 1813 pavements were found on an average of 12 ft below the surface. The stones in the pavements were polyangular in shape, and were from 4 to 5 sq ft in size, and 12 to 14 in deep, laid with close joints. Modern blocks in Rome are described as being two cubes long, and, when set up, as having an area of 10 sq in. This would give a block about 7 in long, 3½ in deep, and 3½ in wide.

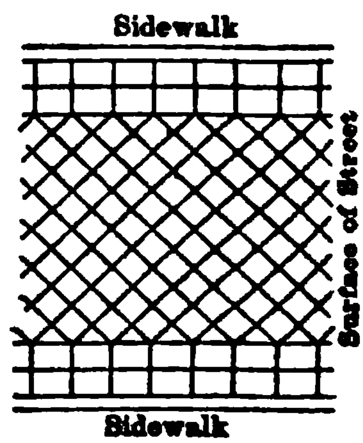

Fig. 3

Square granite blocks were first used in Westminster, England, in 1761, and in London in 1776.

In 1912 streets in New Orleans, La., were paved with blocks approximately 2 ft long and 1 ft wide. These blocks were said also to be 1 ft deep, so they could be, and were, turned over and relaid when the original surface became rough. These blocks came to New Orleans in vessels as ballast, some having been used for 60 years. In 1849 Broadway, New York

City, was paved as far north as Franklin St. with what was called Russ blocks. These blocks were from 2 to 3 ft square. About 5 years after this pavement was laid, it became so slippery that it was necessary to cut grooves in the blocks to give horses a foothold. Large blocks were not satisfactory, as, unless laid absolutely even and with close joints and on a solid foundation, under traffic they would soon become uneven and, unless of a particularly gritty character, would become smooth and slippery. Their use, therefore, was discontinued in progressive cities, as they could not be considered desirable from any standpoint.

In the course of development blocks of smaller size, approximately 6 and 7-in cubes were adopted in Europe and eventually in this country, taking the place of the cobblestone and forming the improved pavement. Later, came the modern oblong block, which was laid in New York City about 1877.

Guidet Pavement. In 1865 a patent was issued to Charles Guidet for laying granite pavement, the distinctive points of the pavement upon which the patent was based being: (1) Stones are bounded by six faces, the two opposite faces being parallel with each other; (2) the width of the joints running transversely to the street is comparatively wide; (3) the width of the joints running longitudinally to the street is comparatively narrow. A portion of Atlantic Ave., Brooklyn, N. Y., was improved with this pavement, and blocks measured there were found to be from 18 to 20 in long and from 5 to 6 in in width.

2. Foundations and Crowns

Foundations. Practically all large cities at the present time are using cement-concrete foundations. Vienna and Paris are, however, exceptions. The latter city in 1913 had but 8% of its stone block pavement laid on concrete. It is assumed, therefore, that all stone block pavements are laid on a concrete base. The thickness and composition of this base should depend upon the character of the traffic it sustains. If a pavement is practically a masonry construction, so that it is one broad sheet, the weight will be distributed over the base and not cause a great pressure upon any small portion. If, however, the blocks are not firm, so that a wheel load is liable to be transmitted from a block directly to the base, more careful attention must be given to the foundation. In Glasgow, where loads of 100 tons are carried upon wheeled vehicles, no thicker base than 6 in is ever used. It should be said, however, that the wheels upon which these loads are carried have tires 15 or 16 in wide, so that even with the heavy loads the weight is distributed over a considerable surface. It would seem, as a general proposition, that on a pavement where such loads were liable to be borne at very frequent intervals, special provision should be made for the foundation.

Crowns. Very few engineers agree as to the exact amount of crown to be given to a pavement, and they also vary it according to the character of the material. A pavement is laid in a street for use, and if it could be kept an absolutely horizontal plane it would be more desirable for traffic. It is necessary, however, to give it some crown in order to have the water run to the gutters. Any excess of crown beyond this requirement reduces the efficiency of the street to a certain extent. The worst possible way a horse can slip is sidewise, and for that reason the transverse slope should be kept as slight as possible to allow the water to flow to the sides freely. Formulas have been worked out by different engineers correlating the width of the roadway with the longitudinal grade, so that on a steeper grade the crown might be made lighter. It would

seem, however, that, as the only object of the crown is to allow the water to flow freely to the sides, a slope that would permit this on a light grade would not be detrimental to traffic on any grade, and it does not seem that there is any necessity of elaborate formulas to determine this. Fig. 4 represents the half cross-section of a stone block pavement.

Crowns for Different Widths of Roadway. Assuming the roadway of the street to be 30 ft wide, and adopting a total crown of 4 in, which does not inconvenience travel, the fall towards the gutter of the central one-third will be at the rate of 9 in per 100

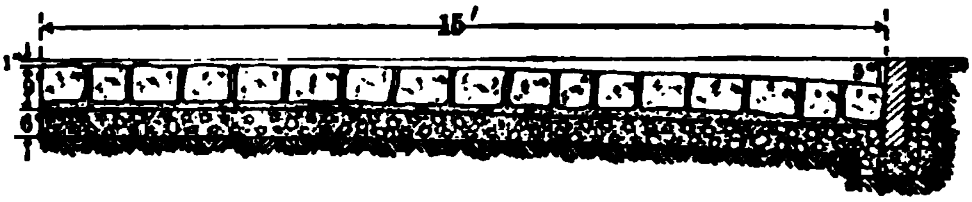

Fig. 4

ft, which is sufficient for drainage; the fall of the second one-third towards the gutter will be at the rate of 27 in per 100 ft; while that of the one-third adjacent to the curb will be at the rate of 44 in per 100 ft. Of course, the center of the roadway would be comparatively flat, but the rates above given will give sufficient drainage, altho possibly 5-in crowns could be used without damage with a stone block pavement. Table I gives the fall from the center to the gutter of each third of the roadway, with

Table I

Width of Road-way	Crown	Fall Towards Gutter in Central Third of Roadway	Rate per 100 Ft	Fall Towards Gutter in Second Third of Roadway	Rate per 100 Ft	Fall to Gutter in Third of Roadway Adjacent to Curb	Rate per 100 Ft
24 ft	3 in	1/3 in	8 1/3 in	1 in	2 ft 1 in	1 2/3 in	3 ft 6 in
30 ft	4 in	4/9 in	9 in	1 1/3 in	2 ft 3 in	2 2/9 in	3 ft 8 in
30 ft	6 in	2/3 in	13 1/3 in	2 in	3 ft 4 in	3 1/3 in	5 ft 6 in
36 ft	5 in	5/9 in	9 1/4 in	1 2/3 in	2 ft 4 in	2 7/9 in	3 ft 3 in
48 ft	6 in	2/3 in	8 1/3 in	2 in	2 ft 1 in	3 1/3 in	3 ft 6 in
60 ft	8 in	8/9 in	8 8/9 in	2 5/9 in	2 ft 3 in	4 5/9 in	3 ft 9 in

different widths and with different crowns. Under the heading of 30-ft roadways figures are given for the 6-in crown as well as the 4-in, showing how very materially the side slope increases with the crown, and this side slope, in slippery weather, is much more damaging to horses than a straight horizontal slope. These figures are recommended as the proper crown on all level streets of improved pavements, except the 6-in crown on a 30-ft roadway. The curve of the pavement is in reality a parabola, but in the distance used is practically a circle. It can be best laid out on the crown by stretching a line from curb to curb, and measuring the ordinates down from the line at any desired interval according to the width of the street. The length of the ordinate can be determined by the simple formula $O = C\ (D/R)^2$, in which D is equal to the distance from the center to any point in feet, R equals one-half of the width of roadway, C equals the crown in inches, and O equals the ordinates in inches.

Relation of Crowns and Gutters. The foregoing principles will work out satisfactorily when the curbs are set at the same level on both sides of the street. It often happens, however, that on side hills where the natural slope of the ground is considerable, it is impracticable to have the curbs on the longitudinal streets at the same elevation, and sometimes there is a difference of 1½ or 2 ft. In an old, improved

section it is extremely difficult to vary conditions much in repaving without undue damage to private property. Slight inequalities in the curb are not very objectionable, and they can be equalized to a great extent by varying the depth of the gutters. On an ordinary roadway 30 or 40 ft wide, the depth of the gutter should not be over 5 or 6 in. If, however, the roadway be wider, it will possibly be advisable to make the gutter deeper, but only in very exceptional cases should it be allowed a depth of 9 in; and, on account of the liability of overflow in case of heavy storms, it should not have a depth of less than 4 in, except under extraordinary conditions. Too deep a gutter also makes too great a step for pedestrians. If it should be assumed, then, that the minimum depth is 4 in and the maximum 9 in, a difference of elevation of the curbs of 5 in can be overcome by making the depth of the gutter on the high side 9 in and on the low side 4 in. This would make the bottoms of the gutters at the same elevation. This method can be pursued on roadways 40 ft or more in width even when there is a foot difference in the elevations of the curbs. When, however, the difference becomes as great as 1½ or 2 ft, another method must be used. In such a case by making the highest part of the pavement one-fourth of the distance out from the highest curb, and then sloping regularly to the low side, very good results can be obtained with a roadway of 40 ft. In a case like this the height of pavement above the gutter on this quarter distance out from the curb should be a minimum elevation above the gutter, say 2 in, which, if the maximum depth of gutter be used, would make the highest part of the pavement 7 in below the curb. If the elevation of the lower curb were 2 ft below the upper and a minimum of 4 in in depth used, there would be a fall from the highest point of the pavement to the bottom of the gutter on the low side of 21 in, which would be equivalent to giving a roadway of 60 ft a crown of 21 in. This is excessive, and not desirable, but it is probably the best treatment of the surface that can be given; and if the lower curb be only 18 in below the higher, the fall will be only 15 in, which will not be particularly objectionable.

Effect of Car Tracks on Crowns and Gutters. This plan is based upon the understanding that no street-car tracks exist in the street. When, however, tracks are present, the problem is complicated and it is practically impossible to give a satisfactory treatment to the street surface. The general treatment, however, must be the same, namely, a deep gutter on the high side and a shallow one on the low side. While the rails of each track must be level, it does not follow that the tracks themselves should be at the same level, altho it is preferable that they should be. If the difference between the two curbs be excessive, it is permissible, tho not desirable, to lay the two tracks at a difference of elevation of 3 in, and it often happens that it is necessary on the high side to have the fall from the gutter to the tracks. On a 40-ft roadway two tracks will occupy practically 15 ft in the center, leaving but 12 ft on each side of the tracks, so that there is but small space in which to overcome the difference in elevations of the two sides. When extreme cases exist, great care should be taken to get every advantage possible in establishing the grades of the tracks so that the roadway may be as favorable to traffic as possible.

MATERIALS

3. Physical Properties of Rock for Stone Blocks

In order to make a good paving block, stone should be of an even texture, hard, tough, and durable. It should wear smoothly, so that the surface of the pavement will be practically of the same contour even after it is worn down to a considerable extent. This last quality is important and an exceedingly difficult one to obtain. Apart from its wearing qualities, it should be of such texture as to break smooth and easily, so that a well-shaped block can be obtained without too great cost for labor. It should have sufficient crushing strength to sustain easily, on the side of the blocks used, any load that might come upon it. It should not be too hard, otherwise it will wear smooth and be slippery, and unless the blocks are laid with close joints the edges will round off, giving the block the so-called turtle-back appearance and make the pavement rough and of a cobblestone character, even when the blocks are really not much worn. In

America, stone blocks are made of granite, sandstone, trap rock, and limestone, altho the latter two are used to so slight an extent that they need not be considered seriously.

Granite. This stone is found very widely scattered over the United States, and is very valuable as a paving material. It exists largely in New England, especially on the coast. It breaks freely and with a smooth fracture in most varieties so that it is easily cut up into the desired sizes for paving blocks; and, being on the coast, the blocks are cheaply transported, so that this material is used to a great extent in Boston, New York, Philadelphia, and other cities near the seaboard. It varies considerably in hardness, and in some cities this is recognized by specifying hard granite and soft granite, the idea being that on streets of lighter traffic a softer granite is not only just as good but preferable, as on lighter traffic streets the wear is not so great and the blocks maintain a smooth surface and one that is not slippery. If, however, the traffic is heavy, the hard granite should be used, and the slipperiness prevented as much as possible by the joints between the blocks.

In 1897 Kent Ave., Brooklyn, N. Y., was paved with granite on concrete, with one of the best granites that comes to the New York market. The street had two lines of street-car tracks, and was used at that time to a great extent by the sugar manufacturers in carting sugar. These loads weighed from 6 to 8 tons, and were generally driven along the street with one wheel on one of the rails, so that the outside wheels ran in the same place. In 6 months an appreciable rut had developed in the blocks and also in the cross walks, and employees of the sugar refineries were sent upon the street to divert the traffic. Even then ruts soon developed, as, on account of the car tracks and the heavy loads, it was not possible to use the street from side to side as it could have been used had there been no tracks. An ordinary granite block would have lasted a very short time.

A so-called granite, but really a jaspar, was used in Omaha, Neb., after paving work was begun there in 1883. This stone was exceedingly hard, but did not break very well, and, while it showed almost no wear under traffic, it became so smooth that long before it was worn out it had to be taken up on account of its extreme slipperiness.

Sandstone. There are three kinds of sandstone used to quite an extent in the United States: That which is known as Medina sandstone, found near Rochester and Buffalo, N. Y., and which furnishes the material for the stone pavements of those cities as well as of Cleveland; the Kettle River sandstone, which is found in Minnesota and is used to quite an extent in St. Paul, Minneapolis, and vicinity; the Colorado sandstone, which comes from the quarries near Denver and furnishes the stone for pavements in that city and in Omaha, Neb.

MEDINA SANDSTONE. This stone is generally deep brown or red in color, tho sometimes gray, the coloring matter being oxide of iron. The principal quarries are located between Brockport and Lockport, in Monroe and Niagara Counties, N. Y. It is found in thin layers, so that it is easily gotten out in blocks and at comparatively low cost. It has good crushing strength, but wears much more rapidly than does granite; it is said, however, to have lasted from 40 to 50 years in pavements in the cities where it has been used. It varies in hardness according to localities, and for that reason, when used in pavements, the blocks should all come from one quarry, or ledges of similar formation, so that the blocks will be of the same degree of hardness and the wear under traffic uniform. These blocks can be laid so as to be very smooth, and, on account of the character of the stones, they are never slippery.

KETTLE RIVER SANDSTONE. The quarries from which this stone is taken

are situated at Sandstone, Minn., about half-way between Minneapolis and Duluth. The stone is extremely gritty and somewhat harder than the Medina. It makes an exceedingly durable paving block, and is easily cut with smooth faces and sides. It has a compressive strength of from 12 000 to 13 000 lb per sq in. It is extremely popular as a paving material in the localities to which it is tributary. It can be laid with close joints, so that a very smooth surface can be obtained for the finished pavement.

Colorado Sandstone. This stone is found in Boulder County, Col., to a large extent. It varies in color from gray to light red, according to the composition of the iron compounds, altho the character of the two kinds is practically the same. It is found in layers from 1/8 in to several feet in

Table II.—Test of Physical Properties of Granite Blocks

Material	Location	Crushing Strength	Hardness	Toughness
Granite*	Rion, S. C.	25 790	18.5	11
Granite*	Stone Mountain, Ga.	19 240	18.2	9
Granite*	Redgranite, Wis.	33 880	19.0	14
Altered Syenite Porphyry*	Salisbury, N. C.	25 450	19.2	21
Ferruginous Sandstone*	Columbus, Ohio	21 800	16.5	11
Altered Granite Porphyry*	....	42 480	19.1	28
Granite†	Mt. Airy, N. C.	21 528	....	..
		19 884	....	..
		.....	18.4	4
Granite†	Swans' Island, Me.	15 435	....	..
		19 458	....	..
		.....	19.1	8
Granite†	Roberts' Harbor, Me.	24 826	....	..
		27 842	....	..
		.....	19.0	9
Granite†	Long Cove, Me.	36 895	....	..
		29 862	....	..
		.....	18.7	9
Granite†	Waldoboro Quarry, Me.	24 658	....	..
		29 847	....	..
		.....	19.1	8
Granite†	Waterford, Conn.	25 972	....	..
		29 670	....	..
		.....	18.8	10
Granite†	Vinal Haven, Me.	29 422	....	..
		27 908	....	..
		.....	18.9	11
Granite†	Alexandria Bay, N. Y.	21 668	....	..
		22 167	....	..
		.....	18.5	10
Granite (Sea Green)†	Rockport, Mass.	20 960	....	..
		21 280	....	..
		.....	19.2	8
Granite (Bay View Gray)†	Rockport, Mass.	28 978	....	..
		81 685	....	..
		.....	19.3	12
Granite (Rockport Gray)†	Rockport, Mass.	19 128	....	..
		.....	19.8	8
		25 498	....	..
Granite‡	Barre, Vt.	20 000	....	..
		20 222	....	..
		22 000	18.9	10
Granite‡	Gloucester, Mass.	25 980	19.4	13

* U. S. O. P. R.
† Bureau of Highways, Borough of Manhattan, New York City.
‡ Bureau of Highways, Borough of Brooklyn, New York City.

thickness, and splits easily along the cleavage planes, breaking readily at right angles, so that it is formed into good paving blocks without an undue amount of labor. It is hard and tough, and wears well and smooth in a pavement. It is never slippery, even when smooth, and when laid on an unyielding base will, after a little wear, present a smooth and pleasing surface. It has a crushing strength on the bed of 10 000 to 12 000 lb per sq in, and, on edge, a strength ranging from 12 000 to 17 000 lb per sq in.

Trap Rock. This material has never been used to much extent in the United States, except in cities near the Hudson River. It is found in great quantities on the west bank of the Hudson, and when the Belgian block was first introduced in this country, trap rock was almost entirely used for its manufacture. It is extremely hard and will sustain a large amount of traffic without much wear, but soon becomes smooth, and its character is such that it is made into smooth, well-shaped blocks only at great expense. A few blocks have been used of the oblong shape similar to those of granite, but, on account of the expense of manufacture, to a very slight extent, and its use has been discontinued almost entirely as a paving material.

Whin Stone is used in Glasgow for paving, but under specifications similar to those provided for granite. The City Engineer of that city, in writing to the American Consul, says of this stone: "Whin stone, principally from quarries around the city, is heavy and close grained, and, while not so lasting as granite, lasts as long under the lighter traffic to which it is subjected in the minor thorofares where whin paving is adopted. It is not so slippery as granite, and on this account is used in several of the heavy traffic streets where the gradient is pretty heavy. Whin metal, from the same quarries, is also largely used for macadamizing purposes."

Tests. The Spec. Com. Mat. Road Cons., Am. Soc. C. E. recommends that the following tests on stone blocks be made: Specific gravity, absorption of water, abrasion, toughness, hardness, and crushing strength. Methods for making the above tests are given in Sect. 11. Table II gives the crushing strength, hardness and toughness of rocks from several quarries where stone blocks are manufactured.

4. Manufacture and Size of Blocks

Manufacture of Blocks. Granite paving blocks are practically all made by hand labor; no machinery has yet been invented that will produce blocks satisfactorily and economically. It takes the best of stone that is carefully quarried on the rift to make blocks so that they will break clean and smooth. The granite is first quarried into dimension sizes from large masses of stone by day labor, generally in blocks 36 in on the rift for the width of the block and 40 in for the depth, all in random lengths, so that when the pieces are drilled and split, blocks from 4 to 4½ in wide and about 5 in deep will be produced. The stock is usually transported by railroad and dumped into the paving cutters' berths, so-called, and there drilled and fitted into the finished block. The paving block makers earn, on an average, $15 per week. The blocks are cut by the piece, for which the block makers receive from $25 to $26 per thousand for standard blocks. The average number a man makes in a day of 8 hr is about 100. The blocks are inspected from day to day as they are being made, and again when they are loaded into cars or on board vessels for transportation to the various cities. The improved blocks, 8½ to 12 in long, 3½ to 4½ in wide, 4¾ to 5¼ in deep, will lay about 28 to the sq yd; the special improved blocks, 6 to 10 in long, about 32 to the sq yd. The smaller the block, the closer the joint.

Size of Blocks. Just what is the best size for a stone block has not been determined by engineers, as their opinions vary to quite an extent, depending upon the exact character of the stone to be used and also upon the individual ideas of the engineers themselves. It is generally conceded, however, that for heavy traffic streets an oblong block is best.

LENGTH. As it is extremely desirable that there be as few joints as possible parallel to the line of traffic, the blocks should be made comparatively long. As, however, all streets are laid with a certain crown, the blocks must not be so long as to give an uneven bearing on the foundation or be liable to tilt or tip up under traffic, nor so long as to easily break when extremely heavy loads are driven over them. Also they should not be so long as to make a block that would be too heavy for pavers to handle easily.

WIDTH. The blocks should be of such width as to give a good foothold for horses. On account of the character of granite, for instance, the surface of the stone itself can offer but a slight foothold for horses. In cities most horse shoes are made without calks, and unless the horse is able to get a foothold in the joints between the blocks, especially after the pavement is somewhat worn, his efficiency as a draft animal will be very much reduced, and he will also be liable to slip and injure himself. The blocks, however, must not be too narrow, otherwise the joints would be too many and the blocks would be liable to be unstable on the foundation. In the determination of the width of the block, however, the character of the stone and the traffic should be taken into consideration. As the sandstones are so much less slippery than granite, wider blocks are permissible, and if traffic is not made up of heavy units, the necessity of joints for foothold for horses is not so great.

When, just previous to the Spanish-American War, a contract was made for paving in Havana, Cuba, the maximum width of blocks was made 3 in, because in that city mules were then mostly used for trucking, and their feet being so much smaller than those of the ordinary horse, more frequent joints were required in order to give them the necessary foothold.

The City Engineer of Newcastle-upon-Tyne, England, in speaking of width, says: (22) "A narrow sett is used in order to give better foothold and to obtain a neat appearance in the pavement, but if the sett is not unduly wide, these requirements can be obtained by a greater width than 3 in. Further, with narrow setts giving a correspondingly large number of joints, not only is the noise increased, but the strength of the whole pavement is reduced. With most descriptions of granite the waste of material in producing a sett 3 in in width is considerable. Consequently the cost is about 9% greater than in the production of a sett 4 in in width."

DEPTH. This is probably the most important dimension of the block, and two principles must be considered in its determination: (1) The kind of wear which the pavement must sustain when laid, (2) the stability of the block itself. Very few blocks in a granite pavement are worn out when it becomes necessary to relay the pavement as a whole, but in a series of years the blocks become displaced so that they get an undue amount of traffic, are worn off on the edges, and so become rough and unsatisfactory, when the actual loss in the depth of the blocks is very slight. Therefore what is required is to have a block that is sufficiently deep as to be stable and have sufficient strength to sustain the traffic. As a general rule, and in order to have stability, the depth of the block should be not less than the width, and preferably greater. If blocks are made 5 in in depth there will probably be no danger of crushing when either granite or the best sandstone is used.

When the oblong shaped granite blocks were first used in the United States, they were given a depth of from 7 to 8 in. The blocks, however, were laid on a sand

foundation, and it was thought that a permissible variation of 1 in would not be detrimental to the pavement, as the sand base would take up the inequality, and by allowing this variation the blocks could be made more cheaply. When, however, the concrete base was used and it was not necessary to have so much inherent stability in the block itself, a block of much less depth was used, and in 1912, after a conference between the engineers of New York City and vicinity and the material men furnishing the granite to this locality, the following specification was adopted: "Blocks shall be of the following dimensions: Not less than 8 nor more than 12 in long on top; not less than 3½ nor more than 4½ in wide on top; not less than 4¾ nor more than 5¼ in deep."

Another form of stone that can hardly be called blocks is used in Russia, making what is called kidney pavement. These stones are said to be of irregular form, either entirely undressed or little dressed. The kidney setts are divided by sizes into four classes: large, about 10 in in length; medium, about 8 in in length; small, about 6 in in length; and fine, about 4 in in length, and the setts are therefore used as large, medium, small, or fine. The medium and small kidney pavements are generally used for the traffic section, the large for paving slopes, and the fine for strips of road surface on which there is little or no traffic. Stones not very much better in character than those just described could be seen in the pavements of Baltimore in 1915.

Table III shows the sizes of blocks used in many of the principal cities in this country and Europe:

Table III

City	Length Inches	Width Inches	Depth Inches	Remarks
Boston	8 to 12	4 to 4.5	5 to 5.5	Special cut
	9 to 14	3.5 to 4.5	7.5 to 8	Large
Brooklyn, N. Y.	8 to 12	3.5 to 4.5	4.75 to 5.25	
Chicago	6 to 10	3.75 to 4.25	3.75 to 4.25	
	8 to 12	4 to 5	5	
Cleveland	8 to 12	3.5 to 5	4.75 to 5.25	Granite
	8 to 13	3.5 to 5	6 to 6.5	Sandstone
Manhattan, New York City	6 to 10	3.5 to 4.5	4.75 to 5.25	
Philadelphia	8 to 12	3.5 to 4.5	5 to 5.5	
Rochester, N. Y.	7 to 12	3 to 6	6 to 6.5	
	7 to 12	3 to 5	4.75 to 5.25	Sandstone
Budapest, Hungary	7.2	7.2	5.6	Light traffic
	7.2	7.2	7.2	
Dresden	7.2 to 8.8	5.6 to 6.8	6.8 to 7.6	Half trimmed
	7.2 to 10	4.8 to 6.4	6.4 to 7.2	Ordinary stones
Edinburgh	Ordinary	4	6	
Elberfeld, Germany	7.2	4.8	6.4	Heavy traffic
	6.4	5.6	6.4	Medium traffic
	6.4	4	6.4	Light traffic
Frankfort, Germany	Minimum 7.2	6 to 6.8	6 to 6.8	
	Minimum 7.2	5.2 to 6	6 to 6.8	
	Minimum 5.6	4.8 to 6.4	6.4	
	Minimum 4.8	4 to 6	5.2 to 6.4	
Glasgow	...	3.5 to 4	5.6 and 7	
	4	4	4, 5, 6 and 7	
Hamburg	4.8 to 9.6	4 to 6	7.6 to 8.4	
	4.8 to 9.6	4 to 6.4	6.8 to 8.4	
	6 to 10	4.4 to 5.6	5.6 to 6.8	
London	5 to 9	3 on bed	....	
Manchester, England	5 to 8	4 to 7	6	
Newcastle, England	....	4	6	
	....	6	6	Sandstone
Paris	6.4	4	6.4	

Dressing. After the size of the block has been determined, its character as to smoothness upon its different faces is very important. It can easily

be understood that, in order to have a smooth pavement, the blocks themselves must be smooth, and this applies not only to the top but also to the sides so that the joints may be even and filled with some material that will hold them securely in place. As the class of labor required in making blocks is expensive, an extra amount of work upon the blocks rapidly increases the cost of the pavement. As has been intimated, stones of different texture and character break quite differently, and this one fact often determines whether or not a stone will be suitable for paving material.

In the Conference of New York City Engineers and granite block manufacturers, this question was discussed to a great extent, as it was not desired to specify a block that would require so much labor as to make it unduly expensive even if it made a first-class pavement. The specification in this respect that was finally adopted was as follows: "The blocks shall be so dressed that, after laying, the measurement of the individual joint will show not more than ½ in in width at top and for a depth of 1 in, nor more than 1 in in width in any other part of the joint, provided that not more than one drill hole shall show on the side of the head and none on the end of the head of any block. The head of the block shall be so cut that it shall not have more than ⅜ in depression from a straight-edge laid in any direction across the head and held parallel to the general surface of the block." This specification has been practically adopted by cities in the vicinity of New York and also by the Association for Standardizing Paving Specifications. It was extremely desirable to adopt such a specification, as it made it possible for the granite men to make blocks that would be satisfactory, not simply for one of the cities which they supply, but for all, so that if the demand in any one place should be excessive, blocks originally proposed for one city could easily be diverted to another, thus avoiding any vexatious delays.

The Bureau of Highways, Brooklyn, N. Y., adopted the foregoing specification for grade 1 granite blocks, but for grade 2 granite blocks the specification says that they shall be: "Not less than 8 nor more than 12 in in length; not less than 3½ nor more than 4½ in in width, and not less than 7 nor more than 8 in in depth. The blocks are to be rectangular on top and sides, uniform in thickness, to lay closely and with fair and true surfaces, free from bunches."

Providence, R. I., in 1913 received bids for two kinds of blocks, being practically such as has been described for grade 1 and grade 2, Bureau of Highways, Brooklyn, and the price per thousand blocks was $1 more for grade 2 than for grade 1. The requirements were the same for the character of the stone. It must be remembered, however, that the blocks of grade 2 were very much larger than of grade 1, and, altho not so well dressed, would require more raw material and cost more to transport, which is an important item of granite block pavement. This probably accounts for the difference in price, as it would naturally be expected that the better blocks would cost more. As a matter of fact, in Brooklyn, where contractors buy by the square yard as laid in the pavement, the price for grade 1 blocks is materially more than for grade 2, as it requires 28 of the improved blocks per sq yd and only 22 of the ordinary.

5. Specifications for Stone Blocks

Am. Soc. Mun. Imp. 1916, Specifications for Granite Paving Blocks. "The paving blocks shall be of medium grained granite, showing an even distribution of constituent materials, of uniform quality, structure and texture, without seams, scales or disintegration, free from an excess of mica or feldspar, and equal in every respect to the sample in the office of the engineer.

"Tests. For heavy traffic the granite shall have a toughness of not less than 9 and a French coëfficient of wear of not less than 11. For medium traffic, the granite may have a toughness of not less than 7 and a French coëfficient of wear of not less than 8 if a cement grout filler is used. The above tests shall be made by the methods described in Bul. 44, O. P. R., U. S. Dept. Agr. The average of three tests shall be used for determining toughness and the average of six tests for determining the French coëfficient of wear. Contractors shall file with the engineer at or before the time of bidding, a certificate showing the name and location of the quarry from which it is proposed to obtain the blocks, also a certified copy of a report from the U. S. Dept. Agr., showing the toughness and French coëfficient of wear of the granite which it is

proposed to use. On or before the date of the letting, six specification blocks, made from the granite it is proposed to use, shall be filed with the engineer.

"SIZE OF BLOCKS. The blocks shall be of the following dimensions: Not less than 8 nor more than 12 in long on top; not less than 3½ nor more than 4½ in wide on top; not less than 4¾ nor more than 5¼ in deep. Note: When in the judgment of the engineer, a shallower block than that before specified is deemed desirable, a block 3¾ to 4¼ in wide, 3¾ to 4¼ in deep, and 7 to 11 in long, may be used, provided the granite has a sufficiently high factor of toughness and French coëfficient of wear.

"DRESSING. The blocks shall be so dressed that the faces will be approximately rectangular in shape, and the ends and sides sufficiently smooth to permit the blocks to be laid with joints not exceeding ½ in in width at the top, and for 1 in downward therefrom, and not exceeding 1 in in width at any other part of the joint. The top surface of the block shall be so cut that there will be no depressions measuring more than ⅜ in from a straight-edge laid in any direction on the top and parallel to the general surface thereof. Care shall be exercised in handling the blocks so that the edges and corners shall not be chipped or broken, as blocks otherwise acceptable may be rejected on account of spawling. The blocks shall be sorted and laid in courses of uniform width, except in special cases, as may be ordered."

Am. Soc. Mun. Imp. 1916 Specifications for Sandstone Paving Blocks. "The paving blocks shall be of sound, hard sandstone, free from clay, seams, or defects which would injure them for paving purposes, of uniform quality and texture, and equal in every respect to the sample in the office of the engineer.

"SIZE OF BLOCKS. The blocks shall be of the following dimensions: Not less than 8 nor more than 10 in long on top; not less than 3½ nor more than 6 in wide on top; not less than 4¾ nor more than 5¼ in deep."

Am. Soc. Mun. Imp. 1916 Specifications for Recut or Redressed Paving Blocks. "When the use of blocks recut from old paving blocks is permitted, such blocks must comply with the specifications for quality of stone, as required for new blocks. The dimensions may be varied, depending upon the size of the old blocks which are to be redressed, and the character of the pavement which it is sought to obtain."

Boston: "Large 'number one' blocks are to be used. The blocks are to be 3½ to 4½ in wide, 7½ to 8 in deep, and 9 to 14 in long, averaging not less than 11½ in; the edges are to be sharp and straight, forming right angles at their intersections, both horizontally and vertically; the faces are to be straight split and free from bunches and depressions exceeding ½ in and are to be laid with as close joint as possible. Special cut blocks are to be used. The blocks are to be smooth finished on the vertical sides and ends, the edges are to be sharp and straight, forming right angles at their intersections, both horizontally and vertically, and lay close with joints not to exceed ¼ in; the blocks are to be 8 to 12 in long, 4 to 4½ in wide, and 5 to 5½ in deep."

Bureau of Highways, Borough of Brooklyn, New York City: "Granite paving blocks shall be of medium grained granite showing an even distribution of constituent minerals, of uniform quality and texture, without seams, scales or discolorations showing disintegration, free from an excess of mica or feldspar and equal in every respect to the samples in the office of the Chief Engineer."

Chicago Specifications: "Upon the sand cushion shall be set granite paving blocks having a uniform grain and texture, without lamination or stratification, and free from an excess of mica or feldspar. Soft or weatherworn blocks, or those obtained from the surface of the quarry, shall not be used. The blocks shall measure from 4 to 5 in in width, 8 to 12 in in length, and 5 in in depth, and be so dressed as to have substantially rectangular, plane surfaces. Substantially rectangular is interpreted that should a block be chamfered or undercut on the side or end, the same shall be not greater than ½ in. When the blocks are in place, the surface joints shall be not less than ⅛ nor more than ⅝ in in width. Upon the application of a straight-edge to the surface of the block, the variation therefrom shall be not greater than ⅜ in. Upon the application of a straight-edge to the sides or ends of a block, the variation therefrom shall be not greater than ½ in."

Cleveland: "Paving blocks shall consist of the best quality of Medina sandstone or granite, as above specified; the Medina blocks shall not be less than 3½ nor more than 5 in thick, and not less than 6 nor more than 6½ in deep, and from 8 to 13 in long. The granite blocks shall not be less than 3½ nor more than 5 in thick, and not less than 4¾ nor more than 5¼ in deep, and not less than 8 nor more than 12 in long.

The stones to have parallel sides and ends with right-angle joints, all roughness and points of stones to be broken off, so that when set in place they shall have tight joints for a distance of at least 3½ in from the top down; the area of the bottom of any stone to be not less than three-quarters of the area of the top. Top to have a smooth, even surface."

Philadelphia: "Smooth Dressed Blocks: The blocks shall be so dressed that, after laying, a measurement of the individual joint shall show a width of not more than ½ in at the top and for a depth of 1 in, and a width of not more than 1 in in any other part of the joint. The head of the block shall be so cut that it shall not have any depressions more than ⅜ in in depth measured from a straight-edge laid in any direction across the head and held parallel to the general surface of the block. Not more than one drill hole shall show on the head of a block, and none on the ends. An average allowance of not over one block, showing drill hole on side, shall be permitted to a square yard of laid blocks.

"Rough Dressed Blocks: The blocks shall be so dressed that after laying, a measurement of the individual joint shall show an average width of ¾ in. The head of the block shall be so dressed, the surface will be rough and irregular; this irregularity on each block being not less than ¼ nor more than ⅝ in."

Rochester: "Paving blocks shall consist of the best quality of Medina sandstone free from quarry checks or cracks, and shall be quarried from fine grain live rock, showing a straight and even fracture. The material shall be of uniform quality and texture, free from seams or lines of clay or other substances which, in the opinion of the City Engineer, will be injurious to its use as paving material. Blocks shall measure not less than 3 nor more than 6 in thick, and not less than 6 nor more than 6½ in deep, and from 7 to 12 in in length. Stones to have parallel sides and ends, and right-angle joints. All roughness in joints of stone to be broken off, so that when set in place they shall have tight joints for a distance of at least 2½ in from the top down. The top to have a smooth, even surface, with no projection or depression exceeding ¼ in."

Liverpool. For heavy traffic streets, Liverpool uses setts 5 to 8 in long, 4 in wide, and 6¼ in deep. For lighter traffic streets, setts 3¼ in square on top and 5 or 6 in deep are used. These are said to give a good foothold, and are generally referred to as pegtop blocks. On still lighter traffic streets 4-in cubes have been used, but it is stated that the present tendency is for the substitution of pitch macadam for the lightest traffic.

London: "The setts to be carefully dressed and free from protuberance at the sides or on the top surface, to be closed at the joints, leaving only sufficient space for grouting to pass to the bottom."

Edinburgh: "Paving setts shall be newly quarried and obtained from the best parts of the quarry approved of, free from cracks or shakes, and square, dressed thruout in the best manner to within ¼ in of sizes."

In Glasgow, in 1913, the blocks were axed on the top, jointed on the sides and ends, and dressed on the bed, making almost a dressed dimension block. This produced an almost perfect pavement, but cost, even tho material and labor were cheap, $6.25 per sq yd.

Frankfort, Germany: "All material delivered must be hard and durable and from the best strata of quarries mentioned. It must be solid and uniform in hardness and color, and be able to withstand weather, and must contain no cracks, scales, soft spots, or foreign substance, and have no other faults. All stone that is porous, or was exposed to the sun before quarrying, shall be rejected. All stone must withstand hammering and ramming while laying without cracking. Class No. 1A and No. 1B stones for roadways must be regular in shape. The top surface must be even and smooth, rectangular and with sharp corners. The sides must be hammered smooth without hollow spots or sharp points or projections. The bottom surface must be of similar workmanship and parallel to the top surface. Class No. 2A and No. 2B stones for roadways must fulfil the general requirements of stones for Class No. 1. The top surface must be even and have sharp corners, and must not deviate from rectangular shape more than 0.2 in. The side surfaces must be so finished that when laid joints larger than 0.4 in will not ensue. The bottom surface must be parallel to the top. Class No. 3 stones: Top surface must be similar to Class No. 2, side surfaces to be so finished that joints larger than 0.6 in will not ensue; the bottom surface to be as nearly parallel to the top as possible."

Hamburg: "Stones must be of uniform structure, without cracks or foreign substance. The top surface must be even and square, and with full, sharp corners. The bottom surface must be parallel to the top, with a surface at least two-thirds the area of top. The sides must be plumb for a distance of 1.6 in from the top, and from there to the bottom as even as possible. They must not bulge so as to be the cause of large joints, nor have large cavities which would consume too much tar."

In Budapest, Hungary, when cubical blocks are used, it is specified that they shall be dressed with a diamond pointed punch with such exactness that two of them placed together will not give a joint of more than 0.44 in.

6. Cost Data on Stone Blocks

The price of granite blocks, delivered f.o.b. alongside the dock in the vicinity of New York City, depends entirely upon the cost of material, supply and demand. A fair price for the material in 1915, based on above deliveries, is $2 per sq yd for the standard blocks, and $2.30 per sq yd for the special improved blocks, dressed so as to lay with a ⅜-in joint.

CONSTRUCTION

7. Laying the Pavement

Sand Cushion. Upon the concrete base prepared for the foundation there must be spread a cushion of some material in which to bed the blocks, so that they may not only have a firm bearing, but also that there will be some little resiliency to the pavement itself. It is the general practice to make this cushion of sand. When the depth of the blocks ran from 7 to 8 in it was customary to spread 2 in of sand upon the concrete base; this would allow for the difference in the depth of the blocks and give at least 1 in under the deeper blocks. In the present practice, however, when the blocks vary in depth from 4¾ to 5¼ in, 1 in of sand is generally deemed sufficient. The specifications of the Bureau of Highways, Brooklyn, N. Y., call for 1 in of sand for Grade 1 blocks and 1½ in for Grade 2 blocks. The specifications of the Bureau of Highways, Borough of Manhattan, New York City, call for not more than 1 in and sufficient to bring the surface of the pavement when thoroly rammed to the proper grade.

In London the specifications say that the blocks shall be evenly bedded on a thin layer of sand, or other approved material, mixed with lime or cement if so directed, and spread over the concrete foundation. Liverpool requires the blocks to be set upon a bed of fine gravel ½ in thick. Glasgow calls for a sand cushion 1 in in depth, and Edinburgh for a cushion 2 in in depth.

Laying the Blocks. The practice of practically all the engineers in this country is to lay the blocks at right angles to the curb, except at intersections. A few streets have been paved by laying the courses diagonally, and theoretically it is better. While it is possible that the blocks may wear somewhat longer by this method, the extra cost of labor and the waste of material in cutting the blocks at the curb would undoubtedly more than offset the gain of wear, if any, in the pavement itself. Care should be taken by the paver, in breaking joints, to have one block lap the other as much as possible, and in any event not less than 3 in. If the blocks do not break joints by this amount, and traffic should for any reason be led into one track, practically long longitudinal joints would be formed, causing undue wear upon the blocks. Even with a scattered traffic, two or three blocks with a slight lapping of joints will soon cause an appreciable wear, where otherwise none would exist. With short blocks the joints are much more frequent, and for this reason extra care should be taken in the laying.

Blocks Laid Diagonally. In Vienna, and in parts of Hungary, however, it is customary to lay blocks diagonally on streets at an angle of 45° to the curb. The blocks are practically 7¼-in cubes, and often the blocks at the curb, and sometimes at the car tracks, are pentagons, instead of rectangles, so that no cutting or fitting of the blocks is necessary on the street. Figs. 5 and 6 show two methods of laying the blocks diagonally. It will be noticed in Fig. 5 that some of the stones are one and one-half times the length of the cubes. These stones are called binders and are set at the ends of the courses as shown. At intersections the arrangement of the blocks is different from what it is on the street proper. Where cross-walks are used they should be laid in three rows, separated by one or two courses of blocks in line with the curb. These crosswalks should be firmly bedded in sand cushions spread upon the concrete and thoroly rammed to place.

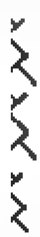

Fig. 5

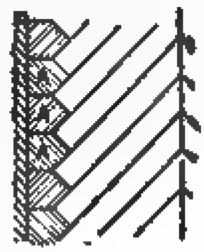

Fig. 6

Laying Blocks at Crosswalks. In the early days it was the custom to lay crosswalks with joints as shown at A, Fig. 7. Under traffic, however, the stones wore quickly along the joints, as the long joints were parallel to them. This was obviated to a certain extent by having the joints cut at an angle and laying the stones as shown in Fig. 8 at B. This was all right for traffic turning corners, as shown by the arrows, for one crosswalk, but, for the other it was as bad as before, for the traffic was parallel to

Fig. 7 Fig. 8

the joints at one of the crossings. This was finally obviated by laying the stones as shown in Fig. 9 where no traffic is parallel to the joint, whether it goes directly across the intersection or turns at the corners. The original method of laying the blocks themselves was the same as to joints as regards crosswalks, and modified in the same way, as shown in Figs. 7, 8 and 9. This latter method is what is known as the herring-bone method, and, while requiring considerable cutting at the sides, it is the best plan to date. With the improved blocks, however, and the smaller joints, the

question of joints is not quite so vital, but too much care cannot be taken to make them as short as possible in the direction of traffic. While granite block pavements have been laid in New York City for many years, still occasionally an intersection laid as shown in Fig. 7 can be seen. It of course makes no difference, as regards wear of the pavement, whether a block is 3½ or 4½ in in width, or whether two adjacent courses have this variation, but it does make a great deal of difference in the appearance of the finished pavement, and it requires very little extra care or expense to prevent it.

Fig. 9

Joints Between Blocks. The question of the width of joints between the blocks is important, and how it shall be solved depends both upon the care and skill of the paver and how well the blocks have been cut. The size of the joint must be regulated according to the kind of filler to be used. If it is proposed to fill the joints with any form of bituminous cement, the blocks cannot be laid too closely; if, however, the joints are to be filled with tar and gravel, as a variation of 1 in is allowed in the width of the blocks, great care must be taken in their selection when the courses are being laid. The Borough of Manhattan, New York City, specifies that the contractor, before he begins work, must notify the Engineer of the width of blocks he will use. This means that the blocks must be selected as to width in the quarry before they are shipped. The joints must be of a size to receive the gravel required by the specifications. If a Portland cement filler is used, the blocks should be set stone to stone, but it is not necessary that the sides be smooth and even.

The Bureau of Highways of Manhattan, New York City, specifies that the blocks shall be laid with a ⅜-in joint, while the Bureau of Highways of Brooklyn requires a ½-in joint.

Chicago: "The blocks shall be laid in contact with each other and in uniform courses across the roadway between the curbs, except at the intersections of the streets, where they shall be laid at an angle of 45° with the center line thereof. Each course shall consist of blocks of the same width, and shall be so laid that all longitudinal joints will be broken by a lap of at least 3 in. Hot dry gravel free from loam and dirt shall be swept into the interstices, and the blocks rammed with a 75-lb rammer to a true surface and a firm bed. No cracked or chipped blocks shall remain in the pavement. When directed by the Engineer the space between the granite blocks and the curb or curb wall shall be filled with a mortar composed of one part of Portland cement and three parts of torpedo sand or limestone screenings. The price bid per square yard for pavement must include all cost of this work."

Cleveland: "Stones are to be set tight together, in uniform rows, breaking joints at least 2 in and resting against stones, in the same and adjoining courses; those of the same class and thickness to be placed together in the same row; rows of similar thickness to be placed together, and set directly upon the earth foundation; no gravel or sand to be placed on top or between as stones are laid. Stones to be set perpendicular to the grade, and in right angle courses across the street, except at street and alley intersections, where the courses are to be set at such angle as the Engineer shall direct. The pavement shall always be laid by the paver standing upon the upper

side of his work; the pavement shall then be subjected to the following treatment by the Contractor, and in such order and to such extent as the Engineer shall direct. The pavement shall be laid to the proper grade and crown of the street by using cords or lines stretched lengthwise of the street and drawn tightly over and touching the top of bed stones set in the ballast, in the usual manner, as directed; these bed stones to be set in rows lengthwise of the street. Stones shall be set from 4 to 6 ft apart each way, as directed, with their tops at the proper grade and crown from the pavement. The lines or cords, when in use, shall always be kept taut and shall extend over not less than three bed stones at a time, or from paving that is laid over not less than two bed stones, making always the three points of support. In placing paving material in the beds in advance of paving, care shall be taken not to disturb the lines nor bed stones when set, both of which shall always be kept uncovered and free; and all paving shall be laid to lines set as here specified."

Boston: "Upon the concrete or gravel base is to be spread a layer of clean, coarse-screened bedding sand, and in this sand the blocks are to be laid in courses of uniform width and depth at right angles with the line of the street, unless otherwise directed by the Commissioner, with close joints, the longitudinal joints broken by a lap of at least 2 in, sufficient sand being used to bring the blocks to the grade and form for the finished roadway after they have been thoroly rammed as hereinafter provided; they are then to be covered and the covering raked and swept until the joints of the blocks are filled therewith; the blocks are then to be thoroly rammed to a firm, unyielding bed, their surface parallel to the grade and crown required, and are then to be again covered and the covering raked or swept as aforesaid; the blocks are then to be again rammed until they are solid and secure at the grade and crown of the finished roadway; no ramming is to be done within 15 ft of the face of the paving that is being laid, and in doing the ramming one rammer is to be employed to every one paver."

Manchester, England, requires that the joints shall be ½ in in width, and those of London that the blocks shall be close at the joints, leaving only sufficient space for grouting to pass to the bottom.

Principles of Joint Filling. The proper filling for joints in a stone pavement is a question that has been discussed for many years and there is much variation in the practice of the engineers in this regard. The objects sought by the filling are: To obtain a waterproof surface, to keep the blocks stable, and to preserve the joints in such a way that they will not be unduly worn under traffic. It, too, has much to do as regards the noise of a pavement, and as the principal objection to stone pavement is its noisy quality, joint filling on this account alone is particularly important. The joint should be waterproof so as to prevent moisture getting down below the blocks and displacing the cushion. It is a serious question whether it is advisable to have a pavement as nearly masonry as possible. This might be true from a wear standpoint alone, but as has been said before, noise is a great objection to stone pavement, and if the pavement be practically monolithic the noise will be very great. The different joint fillers used in the United States are: Sand; gravel, with its interstices filled with pitch; cement grout; or some bituminous compound.

Steele (22) states: "The aim should be for the pavement to be as near masonry as possible, and it is useless to attempt this with the materials and method of applying them now in use. If instead of grouting the joints, the mastic was applied with a trowel during the laying of the setts, it is probable that a fairly permanent water-tight joint would be obtained; the cost of the work would undoubtedly be increased, but as the weakest part of any structure is generally at the joint, any reasonable cost to improve this would be repaid by the longer life of the finished pavement."

Sand Filler. The first granite pavements were laid on a sand base. The necessity of a waterproof joint was not recognized, and, if it had been, it would not have been easy to obtain it with any filler when the blocks were laid upon sand, as they were liable to settle unevenly under traffic and thus break the bond. Sand, therefore, was used for filling the joints.

Bituminous Fillers. The tar pitch or asphalt joint is one which, if successfully made, is very satisfactory. The blocks, however, must be so dressed that they can be laid with close joints, as, if they are large, the quantity of pitch might be so great as to allow the blocks to move in warm weather, or the pitch itself might run. Also the expense of making the joints would be too heavy. It has seemed difficult, however, to get a bituminous filler that will be perfectly satisfactory under all conditions of climate or temperature. This no doubt will be overcome as bituminous joints come into more general use. In Europe, bituminous fillers are the principal type.

Advantages of Bituminous Filler. The great objection to stone pavement is that it is noisy under traffic. Anything that can be done to reduce the noise will add very greatly to the value of granite as a paving material. If granite blocks are so dressed that they will have a joint not exceeding ¼ in, the joint can be filled with a stable bituminous material in such a way as to isolate every block from its neighbor. The noise produced on a granite pavement is caused by the action of the wheel upon the individual blocks. With a stone pavement that is practically a masonry construction, the noise caused by the wheels is transmitted from one block to another, so that soon there is not simply the noise caused by a moving vehicle at the place where it happens to be, but the accumulated noise of its trip over the pavement and the reverberations which must accordingly follow it. If, on the other hand, each block can be surrounded with a non-conductor of noise, so that there is no transmission of noise from block to block, the noise will be reduced to a very great extent, and if the blocks are smooth and they are laid so as to form an unbroken surface in the street, the noise will be still further reduced. The noise made by a vehicle passing over such a pavement would be much less than if passing over one of the old-style pavements with tar and gravel joints.

Pitch fillers came into use soon after the blocks were made of better form so that they could be laid with closer joints and thus be made more stable of themselves, and with the narrow joints they would not require an undue amount of pitch. The first pavement laid in this way was on Fourth Ave., Borough of Manhattan, New York City, between Astor Place and 23rd St., in 1910. The pitch compound was not exactly satisfactory, altho the pavement, which has been in use 7 years, is in extremely good condition and shows very clearly the advantage of this construction over the old method.

Gravel and Bituminous Filler. When the concrete base came into use, it was deemed advisable to fill the joints with gravel, the interstices of which were filled with a compound made of 100 lb of coal tar pitch, 20 lb of asphalt, and 3 lb of residuum oil. The original granite pavements on concrete were laid with a joint from ¾ to 1 in in width, so that fairly large gravel could be used, and the voids were such as to freely allow the bituminous filler to flow, so that when a sufficient quantity was used the joint would be full and water-tight. Coal tar, as is well-known, is subject to changes of temperature, so that a compound that was not brittle in winter would be soft and liable to run in summer, and for that reason the pitch was fluxed with the asphalt and the residuum oil. This method required from 3½ to 4½ gal of the compound per sq yd, and cost in New York City, in 1895, from 35 to 40 cents per sq yd when this portion of the pavement was let to a sub-contractor.

Tar and Gravel Filler. The size of the gravel in a tar and gravel joint

must be governed by the width of the joint, and as to make a joint as a whole successful, the pitch must freely percolate thru the interstices of the gravel, the size of the gravel should be fairly large. It should not be too well graded, as, even with some of the particles large, a gradation can be had that will prevent the free flow of the pitch even when hot. The success of this joint depends mainly upon having the interstices of the gravel completely filled, as without that it is very difficult to keep the joints waterproof, and this is recognized at the present time as a necessity from a sanitary standpoint if from no other. If, then, the joints are made wide enough to use large size gravel, they will wear out on the top under the constant action of the shoes of horses, and the edges of the blocks in turn will be worn and rounded off, soon making a rough and uneven street. Therefore it has not seemed that this method of construction was satisfactory. It is expensive, and the results have not seemed to justify the expense. If it be argued that the joints can be made smaller, which is true, it would be necessary to have the size of the gravel smaller, and thus increase the difficulty of making the joint waterproof. It would seem, therefore, that if the joints are to be reduced, a little more care should be exercised in the manufacture of the blocks and the joints made so small that they could be filled with a bituminous compound, either alone or mixed with sand. It is probable that the practice of filling the joints with tar and gravel will shortly be almost entirely discontinued in first-class stone pavements.

Pitch and Sand Filler. A method following the English practice has been adopted of mixing fine sand with the pitch in order to make it tougher and overcome its tendency to become brittle in cold weather. This has not been in use in this country long enough for an intelligent estimate of its value to be formed, altho everything seems to indicate that it will be successful.

Portland Cement Grout was probably first used in this country for a joint filler in Worcester, Mass., about 1900. The practice then was, after the blocks had been rammed, to fill the joints with fine broken stone and then flush them with a grout formed of one part Portland cement and two parts sand. This was allowed to set a week or 10 days before the street was opened to traffic, and this practice has been followed in that city to a great extent since that time. The pavements so laid are smooth, and, if the joints hold good, wear evenly and are generally satisfactory. This class of filler has been used to quite an extent in Europe, but only in a small way in this country. One great advantage is that, on account of the fluidity of the grout when mixed and its hardness and durability after having set, the joints between the blocks can be comparatively large and the blocks themselves rougher on the sides, as the grout will flow freely in and around bunches and when set makes the whole joint solid and complete. It, too, forms what was referred to in English reports as masonry construction, and, when the joint holds, it probably makes as durable a stone pavement as can be laid.

Disadvantages of Cement Grout Fillers. As the joints are absolutely filled with a hard substance, the surface of the pavement becomes very smooth under traffic, and thus slippery for horses. Pavement, however, thus laid, keeps its form, and for that reason presents a light resistance to traffic. It has, however, several material objections. After being grouted in this manner the pavement must be kept free from traffic from 10 days to 2 weeks, according to the weather, in order to allow the grout to become

thoroly set. This is absolutely necessary, for, if traffic is allowed on the street too soon, the blocks are shaken, the partial set is destroyed, and the joints become little better than if filled with sand. In smaller cities and on minor streets this may not be a serious objection, but in large cities on important streets it is prohibitive. It is also difficult to apply the grout in such a way as to get uniform results over the entire pavement surface. On cement grouted streets, areas 10 or 15 ft square are often seen where the grout has entirely disintegrated, altho the rest of the pavement is in perfect condition. This may be due to the unequal mixing of the sand and the cement, or to the possibility of the sand and the cement being segregated in the process of application. This difficulty, however, will undoubtedly be overcome if cement grout joints come into general use. Another objection is the difficulty of making openings in a cement grouted pavement and repairing it afterwards. It may be said that this is not a legitimate objection, but it must be admitted that, however objectionable they may be, frequent openings must be made in the streets of American cities, and that, if any street pavement cannot be readily and well repaired, it will be used to a limited extent. It is not only expensive to make openings thru the pavement, but a great many blocks are broken and destroyed, and so must be replaced with new. The blocks taken up, even if not broken, are coated with the cement and must be cleaned before being used again. It may be said that this extra cost is not borne by the city, but by the parties who make the openings. This may be true, but the expense is borne by someone, and it must come from the pockets of the property owner either in direct payment to the party who makes the openings or in a reduction of dividends or returns on his investment if the openings are made by corporations. These openings are replaced with difficulty because it is almost impossible in this country to keep traffic from a repaved trench long enough to allow the cement grout to set. It may be argued that this should not be, but as a matter of fact it is, and a different result cannot be easily obtained.

American Methods of Filling Joints. The specifications for joint filling adopted in 1916 by the Am. Soc. Mun. Imp. are included in Art. 9.

The Borough of Brooklyn, New York City, has laid some stone pavements with grouted joints, and in 1915 provided specifications for a cement grout filler, a tar and gravel filler, a refined asphalt joint filler, and a filler composed of coal tar pitch and hot dry sand mixed in the proportion of 1 : 1. The specifications used by the Bureau of Highways for the different fillers enumerated do not vary materially from those herein given.

The Bureau of Highways, Borough of Manhattan, New York City, provided in 1914 for a bituminous joint filler as follows:

"The joint filler used shall be a mixture of paving cement, described hereafter, and hot, dry sand in the proportion of one part sand to one part paving cement by volume, or as much sand up to that proportion as the paving cement will carry. The sand shall be clean and sharp and all of it shall pass a 10-mesh screen. It shall be thoroly mixed with the paving cement by stirring or otherwise. The mixture shall be poured into the joints until they are full and remain full, repouring being done if necessary so that they shall remain permanently filled flush with the surface of the pavement.

"The coal tar paving cement shall be a straight run residue obtained from the distillation of coal tar and shall comply with the following requirements:

1. Melting point shall be not lower than 43° C (110° F) nor higher than 52° C (125° F).
2. Free carbon shall not be less than 20 nor more than 35%.
3. Specific gravity at 25° C (77° F) shall not be less than 1.22 nor more than 1.30.
4. Specific gravity of the distillate to 354° C (670° F) shall not be less than 1.06 at 60° C (140° F) compared with water at the same temperature.

"The Contractor before beginning work on any contract shall obtain from the Engineer a statement in writing as to the melting points desired for that particular contract and a variation of 2.8° C (5° F) either way will be permitted from this melting point, but within the limits as indicated above. The kettles in which the coal tar paving cement is heated on the street shall be equipped with approved thermometers and the paving cement shall be heated to a temperature of not less than 121° C (250° F) nor more than 149° C (300° F) and shall be poured when between these limits.

"The asphaltic paving cement shall be obtained by the distillation of an asphaltic petroleum at a temperature not exceeding 700° C (1292° F), and shall comply with the following requirements:

1. It shall be homogeneous.
2. Melting point shall not be less than 54° C (130° F) nor more than 63° C (145° F).
3. Solubility in carbon tetrachloride shall not be less than 98.5%.
4. Penetration at 25° C (77° F) shall not be less than 60 nor more than 100, the penetration test being made with a No. 2 needle for 5 sec under a load of 100 g, and the penetration at 38° C (100° F) shall not exceed three times its penetration at 25° C (77° F), the condition of time and load being as above established. The Contractor before beginning work shall obtain from the Engineer a statement in writing as to the penetration desired for any particular contract and a variation of not greater than ten points either way from this penetration will be permitted.
5. Ductility at 25° C (77° F) shall not be less than 40 cm at the penetration called for.
6. It shall not lose more than 3% by volatilization when maintained at a temperature of 163° C (325° F) for 5 hr, nor shall the penetration of the residue, after such heating, be less than one-half the original penetration."

Chicago: "After ramming, the spaces between the blocks are to be completely filled with a paving pitch which shall conform to the following requirements:

1. It must be obtained from coal tar only and there must be no admixture with it of any material not obtained from coal tar.
2. Its specific gravity at 25° C (77° F) shall be not less than 1.17, nor more than 1.30.
3. It shall contain not less than 22 nor more than 37% of free carbon, the free carbon being defined as the organic material insoluble in cold carbon disulphide after digesting 12 hr at room temperature.
4. On heating 100 g of the pitch to 315° C (600° F), the distillate shall not exceed 8% by weight. The distillation shall be conducted in an 8-oz asbestos jacketed retort, in which is inserted a 3-in immersion thermometer, the bottom of which extends to within ½ in of the surface of the pitch when in a fluid state, and the temperature increased at the rate of 11° C (20° F) per min until the first drop of distillate is formed, and thereafter at approximately the rate of 1 drop per sec. The total length between the thermometer entering the retort and the end of the adaptor shall be 22 in. Two sheets of wire gauze each 20-mesh fine are placed between the bottom of the retort and the burner.
5. The melting point of the pitch shall be not less than 54° C (130° F) and not more than 60° C (140° F) when obtained by the following method: Five grams of the pitch are molded by hand into the approximate form of a cube. Thru the center of this cube is inserted a Brown & Sharpe gauge bent copper wire, 0.08 in in diameter, from face to face of the cube. The bottom of the cube of pitch and the bulb of the thermometer are placed 1 in above the bottom of a 250 cu cm Griffin form beaker filled with 200 cu cm of water and kept at a temperature of 21° C (70° F) for 15 min. The temperature is then raised 5° C (9° F) per min, until the softening pitch touches the bottom of the vessel, or a tin cover, or paper, or sand, placed therein to catch the melted pitch. The temperature recorded at the instant the pitch touches the bottom is the melting point of the pitch.
6. The penetration of the pitch shall be not less than 75 and not more than 110 as determined by the New York Testing Laboratory Penetrometer. The sample shall be placed in water which is maintained at 38° C (100° F) for not less than 30 min. The penetration shall be taken under water at 38° C (100° F) under a weight of 50 g acting for 5 sec.

"The pitch must be used at a temperature of not less than 149° C (300° F) and not more than 177° C (350° F) and be spread in sections if the Engineer so directs. All joints and edges of the block shall be completely filled with pitch and if, after cooling, the joints are not flush and even with the surface, they should be repoured.

"The Contractor shall provide the Board of Local Improvements with a duplicate delivery ticket for each and every load or tank of paving pitch delivered on the work. This ticket must be signed by the consignor and be of a form approved by the Board of Local Improvements.

"Immediately after the spreading of the paving pitch, and while it is still hot, the blocks shall be covered to a depth of not less than 1/4 in with hot roofing gravel. This gravel must be entirely free from sand or loam, and not exceed 1/2 in in size. All gravel must be clean, washed, dried and heated enough to prevent the chilling of the pitch. The tarring and top dressing must be completed each day to within 5 ft of the face of the blocking."

Cleveland: "Mastic Filler. The mastic joint filler shall consist of a mixture of paving pitch, of a quality hereinafter described, and hot, dry sand, of fineness hereinafter specified, in the proportion of one part pitch and one part sand by volume. The paving pitch shall be a straight run residue obtained from the distillation of coal tar. It shall have a melting point of not less than 43° C (110° F) or more than 49° C (120° F) by the cube method of testing, and shall have a free carbon content of not less than 20 nor more than 35%. The sand shall be fine, clean and moderately sharp lake sand of approved quality; not more than 6% shall pass a 200-mesh sieve and not more than 20% shall be retained on a 40-mesh sieve. The sand shall be thoroly mixed with the paving pitch, either by hand stirring or by a mixing machine of approved construction. At the time of mixing, the sand shall be heated to a temperature of not less than 177° C (350° F) and the pitch shall be heated to a temperature of not less than 93° C (200° F) nor more than 121° C (250° F). After thoroly mixing, the filler shall be poured into the joints to the full depth thereof, repouring until all joints are filled flush with the surface of the pavement. Extra care shall be used at the gutters and around manholes, etc, to effectually prevent leakage of water into the sub-roadway. At the discretion of the Engineer the filler may be flushed into the joints by means of approved squeegees or push brooms. In this event the joints shall be flushed full, the same as where poured. A top dressing of clean, coarse sand shall be spread over the pavement immediately after the filler is applied and while it is still soft and pliable.

"Coal Tar Paving Pitch Filler. The joints or spaces between the bricks or stones and those between the bricks or stones and the curb, railway tracks, around manholes, etc, shall be filled with coal tar pitch, which shall comply with the following requirements: Physical Properties. When in place in the pavement it shall be of such a character that it will adhere firmly to the paving brick or stone and to the curb, and shall be sufficiently plastic to allow for contraction and expansion in the pavement without developing cracks in the joints. It shall be proof against action by water and all acids and alkalis to which the pavement may be exposed. The filler shall be such that it retains its consistency under extreme temperature. The free carbon shall not be less than 25 nor more than 40%. The specific gravity shall not be less than 1.23 nor more than 1.30 at 15.5° C (60° F). It shall have a melting point varying not more than 2.8° from 57° C (5° from 135° F) determined by the cube method.

"Methods of use. The filler shall be heated and poured into the joints to the full depth thereof, at a temperature of not less than 149° C (300° F), nor greater than 177° C (350° F). All joints shall be completely filled to the top. The top dressing of sand shall be spread over the pavement immediately after the filler is applied and while it is still soft. In cold weather the sand shall be heated so as to readily bond with the pitch. Extra care shall be used at the gutters and around catch-basins, etc, to effectually prevent the leakage of water into the sub-roadway.

"Asphalt Filler. The interstices of the brick or stone blocks shall be completely filled with an asphalt filler heated to a temperature of not less than 177° C (350° F) nor more than 232° C (450° F). This asphalt filler shall not contain pitch nor any part of coal tar. It shall contain at least 98% of bitumen soluble in carbon disulphide. It shall remain pliable at all temperatures to which it may be subjected as a street paving filler; it shall be absolutely proof against water and street liquids; it shall firmly adhere to the brick or stone and be pliable rather than rigid. The penetration, with a No. 2 needle, shall conform to the following: 100 g, 5 sec at 25° C (77° F) 25 to 60; 200 g, 1 min at 0° C (32° F) not below 25; 50 g, 5 sec at 46° C (115° F) not above 110. Care should be exercised to completely fill all openings around street structures, and the street shall not be used for traffic until the filler is com-

pletely set. A top dressing of sand shall be spread immediately after the filler is applied and while it is still soft."

Boston: "WITH GRAVEL JOINTS. If the blocks are to be laid with gravel joints, the blocks after being rammed, as aforesaid, are to be covered with clean, coarse-screened sand, thoroly dried by artificial heat if necessary, and the sand is to be raked or swept until the joints are filled therewith; the entire area is then to be covered with a layer of the same sand at least 1 in thick.

"WITH PITCH JOINTS. If the blocks are to be laid with pitch joints, they are to be laid as above, but the covering is to be washed pebbles, equal in quality to the best Long Island white pebbles, that will pass thru a ¾-in screen and will not pass thru a ⅜-in screen when number one blocks are used. If special-cut blocks are used the openings are to be ⅝ and ¼ in respectively. They are to be thoroly heated and raked or swept and the blocks are to be thoroly rammed as aforesaid, and the joints filled with pebbles to within 1 in of the surface; the joints are then to be filled with a paving cement of proper consistency until they will receive no more and are filled flush to the grade and crown of the finished roadway; any cement left upon the top of the blocks is to be covered with dry sand, sufficient to absorb the cement, if so required by the Commissioner; the paving cement is to be obtained by the direct distillation of coal tar and is to be kept at a temperature of 149° C (300° F) while being used.

"WITH GROUT JOINTS. If the blocks are to be laid with grout joints, they are to be laid, covered and rammed as provided for pitch joints and then the joints are to be filled as provided for the pitch joints, but with grout which is to consist by measure, of one part of Portland cement to one part of clean, sharp and fine sand; the cement and sand just before the grout is to be used to be thoroly mixed dry in a manner approved by the Commissioner; enough water is then to be added and the grout thoroly worked with hoes or other tools to the proper consistency."

Philadelphia: "GROUT JOINT FILLER: Immediately after the blocks are laid, sufficient gravel shall be spread over the surface and swept into the joints so as to fill the space between the blocks to a depth of about 2 in from the bottom. The blocks shall then be rammed to thoroly settle and compact this layer of gravel in the joints, and so as to leave no blocks above or below the general surface of the finished pavement. After the blocks have been brought to a uniform surface, grout filler, composed of one part of Portland cement and one and one-half parts of clean, sharp sand mixed with clean, fresh water in such quantity as in the opinion of the Chief of the Bureau is necessary to give the proper consistency, shall be poured into the joints until filled and surplus grout appears on the surface. The grout shall be broomed into the joints, if necessary to fill them, and the operation shall be continued as the grout settles, until the joints are thoroly filled flush with the surface of the blocks, immediately after which the entire pavement shall be broomed to a smooth surface, sufficient grout being applied to bring the surface even with the highest part of any of the blocks. The blocks shall be wetted by sprinkling with water immediately before applying the grout, if dry or heated atmospheric conditions require this precaution to be taken. A squeegee scraper shall be used on the last application of the grout. Within ½ to ¾ hr after the last application has been made and the grout between the joints has fully subsided and the initial set is taking place, the whole surface shall be lightly sprinkled with water and the surplus grout left on the top shall be swept into the joints, bringing them up flush and full. After the grouting is done and a sufficient time for initial set has elapsed, so that a coating of sand will not absorb any moisture from the grout, ½ in of sand shall be spread over the whole surface. When the work is subjected to an air temperature of 24° C (75° F) or more, the sand shall be sprinkled three times a day for 3 days. The highway shall be kept closed to traffic for at least 10 days. Should the bond between the blocks become broken, the joints shall be cleaned out, even if it is necessary to take up and relay the blocks. The part so taken up and relaid shall be regrouted and protected until hardened.

"BITUMINOUS JOINT FILLER, SPECIFICATION A: Immediately after the blocks are laid, sufficient coarse hot gravel shall be spread over the surface and swept into the joints so as to fill the space between the blocks to a depth of about 2 in from the bottom. The blocks shall then be rammed to thoroly settle and compact the first layer of gravel in the joints and so as to leave no blocks above or below the general surface of the finished pavement. The joints shall then be poured one-half full with pitch

filler as herein described and then filled to within ½ in of the surface with hot gravel and again poured with the filler. This last pouring shall bring the filling flush with the tops of the blocks at the joints. The final pouring of the filler shall be immediately followed with a sufficient amount of hot gravel, applied at the joints, to conceal the filler. The gravel shall be clean, washed gravel between ⅛ and ⅜ in in its largest dimension, not over 25% of which shall be of the ⅜- in size. The filler shall comply with the following test requirements: (1) Specific gravity: It shall have a specific gravity between 1.23 and 1.33 at 15.5° C (60° F). (2) Melting Point: It shall have a melting point between 49° and 54° C (120° and 130° F). (3) Free Carbon: It shall contain between 20 and 30% of free carbon. The pitch filler as used on the work shall have a temperature of not less than 121° C (250° F), and shall at no time be heated above 163° C (325° F). In applying the gravel and pitch, care shall be taken that the block laying is closely followed by the filling, and in no case shall the pavement be left over night, or when work is stopped, without the filler being completed. In case of rain stopping the filling operation before it is finished, the joints shall be protected by the use of waterproof canvas or other means so as to exclude moisture or water, and, under no circumstances, shall the filler be poured into wet joints.

"Bituminous Joint Filler, Specification B: Immediately after the blocks are laid, sufficient coarse, hot gravel shall be spread over the surface and swept into the joints so as to fill the space between the blocks to a depth of about 2 in from the bottom. The blocks shall be rammed to thoroly settle and compact the first layer of gravel in the joints and so as to leave no blocks above or below the general surface of the finished pavement. The joints shall then be poured one-half full with a bituminous filler as hereinafter described, and then filled to within ½ in of the surface with hot gravel and again poured with the filler; this last pouring shall be flush with the surface of the blocks at the joints. This final pouring of the filler shall be immediately followed with a sufficient amount of hot gravel applied at the joints to cover the filler. The gravel shall be clean, washed gravel, between ⅛ and ⅜ in in its largest dimension, not over 25% of which shall be of the ⅜-in size. The asphalt filler to be used in filling the joints between and around the paving blocks shal. be a bituminous material, either natural or artificial, entirely free from coal tar, or any product of coal tar distillation. It shall be waterproof, free from water or decomposition products, shall adhere firmly to the paving stones, and shall remain ductile and pliable at all climatic temperatures to which it may be subjected in actual use, and shall not run in the joints in the hottest temperature of summer, nor become hard or brittle thru the action of frost. The asphalt filler shall conform with the following requirements:

1. Solubility: It shall contain not less than 98% pure bitumen soluble in carbon disulphide. Of the total amount soluble in carbon disulphide, 98.5% shall be soluble in carbon tetrachloride.

2. Penetration: When tested by the Dow method with a No. 2 needle weighted with 200 g and operating for 1 min at 0° C (32° F), it shall have a penetration greater than 25. When tested with a No. 2 needle weighted with 50 g and operating for 5 sec at 46° C (115° F), it shall have a penetration not greater than 110. When tested with a No. 2 needle, weighted with 100 g and operating for 5 sec at 25° C (77° F), it shall have a penetration between the limits of from 25 to 60.

3. Viscosity: One-half gram of the material when made into a ball shall not melt and drip thru an aperture 1 mm in diameter at less than 93° C (200° F)."

Rochester: "If a paving pitch filler is used, the joints shall be filled with clean, dry, hot gravel of proper size as herein specified, heated in pans especially provided for that purpose, and poured from cans having small spouts and thoroly settled in place with wire picks until the level of the gravel is at least 2 in below the top of the pavement. The gravel used between the blocks shall be of such size as will pass thru a sieve having 4 meshes per sq in, and be retained on a sieve of 64 meshes per sq in, and must be screened when dry."

European Methods of Filling Joints.

Manchester, England: "The joints to be filled with ⅜-in chippings of limestone or other approved stone, and to be flushed with a preparation of pitch and tar of approved quality thoroly boiled, and mixed in proportions satisfactory to the Surveyor; the pavement to be lightly covered with paving chippings."

London: "The stones to be well rammed and back rammed, at the option and as

directed by the Engineer, to a uniform surface, and jointed with a bitumen composed of tar, pitch and creosote in approved proportions, and as the work proceeds to be well flushed with sharp Thames sand and cement or lime, as may be directed, in the proportion of 5 to 1, and coated if so directed, with fine hoggin. If the Engineer shall so direct, the bitumen shall be omitted and the setts entirely grouted up with three to one cement grout."

Liverpool: "The joints shall then be carefully grouted until perfectly filled with a hot composition consisting of coal pitch and creosote oil, and finally the pavement shall be covered with ½ in of sharp gravel.

"Special Coal Tar Pitch. The pitch shall yield no matter volatile below 270° C (518° F) when subjected to dry distillation, and its total volatile organic matter shall not fall below 30%. It shall not contain more than 80% of its weight of matter insoluble in petroleum spirit of 0.700 specific gravity (boiling) and must be free from extraneous matter, such as sand and grit. It must twist fairly after immersion for 2 min in water at 60° C (140° F), but not under 55° C (131° F).

"Special Creosote Oil. The oil supplied shall be obtained exclusively by the distillation of coal tar, and shall not contain any portion of the distillate obtained below 240° C (464° F). None of it shall re-distill below 240° C (464° F). The oil as obtained by distillation of coal tar shall not be treated in any way, either by the addition of any coal tar product, or by the extraction of any of its constituents, excepting such extraction as may be necessary to comply with the following clause. It shall contain no moisture. It shall contain no solid matter at 15.5° C (60° F) and shall have a specific gravity of not less than 1.075 taking water as 1.00 at 15.5° C (60° F). It shall contain not less than 40% of its constituents that do not distill over below 320° C (608° F) and the 60% which does distill over below 320° C (608° F) shall contain 10% of tar acids, to be extracted by soda, specific gravity 1.125 (water 1.00)."

The Edinburgh specifications state that the joints shall be filled flush with boiling hot pitch, prepared and tempered with creosote oil, and the specifications for the same are as follows: "The asphalte for grouting causeway joints shall be composed of best quality pitch and creosote oil, boiled together in proportions of about 1000 lb pitch to 15 gal oil. The pitch shall be free from grit or sand, but shall contain a sufficient proportion of heavy non-volatile oils. The creosote oil shall be obtained only from coal tar, and be of at least 1.060 specific gravity, at 15.5° C (60° F). The mixture shall be tempered so that, when boiled, and cooled in water to 15.5° C (60° F), it shall be capable of stretching out to fine threads, at least 36 in long, before rupture; and, with a detached 3 ft length, be capable of striking a hard blow on any smooth surface without cracking."

Glasgow, which awards contracts for 3 years and furnishes the blocks, provides that the paving shall be well grouted with cement or pitch grout, as directed, and shall then be covered with sand ¼ in in depth. The following are the requirements for the pitch and cement grout. Pitch grout shall consist of pitch and oil made from pure coal tar, manufactured in gas-works by the destructive distillation of coal in close retorts. No blast furnace, iron-works, or coke-oven pitch or oil will be allowed to be used. The oil shall be of a specific gravity of from 1.032 to 1.050 at 15.5° C (60° F). The flash test shall not be under 47° C (116° F). Sufficient oil shall be used to produce a plastic grout. The grout shall be boiling hot when used. The Contractor shall intimate to the Master of Works the names of the persons from whom the pitch and oil are to be obtained. The pitch boilers shall be so constructed that the vapors from the boiling material shall be conveyed into the furnace, which shall be fired with the best coke. No coal shall be used. When the Master of Works considers it necessary, crushed granite shall be used for partly filling in the joints of the setts. The granite must be kiln-dried, and then passed over a riddle of ¼-in mesh to remove all sand and dust, and shall be laid in the joints in two layers. Previous to the granite being put between the joints, pitch shall be run in to the depth of 1 in, the first layer of granite shall then be put in, and be thoroly grouted with pitch; the second layer of granite shall then be put in to fill the joints level with the surface, and be also thoroly grouted. One ton of crushed granite shall do not less than 240 sq yd."

In certain cities of Great Britain, where the character of stone block work was reported to the Third Int. Road Congs. London, 1913, the following fillers were used:

Aberdeen, mixture of pitch and tar; **Bradford**, pitch; **Sheffield**, mixture of pitch and tar, or cement mortar.

Inspection. The inspector who has charge of the construction of a stone block pavement must watch carefully to see, not only that the requirements of the specifications are carried out, but must watch in detail the workmen so that the little things, which often add so much to the general result, will be well done. For instance, it is extremely necessary that the ramming be carried on carefully and the blocks firmly bedded in such a way as to leave the surface true and even, so that when heavy traffic comes upon the blocks, individual blocks will not be depressed below those adjacent and thus deform the surface. Special care should be given to the joints when the blocks are laid, as after they are rammed and trued up, the width of the joints always is larger than before, probably due to the fact that the blocks are not always set vertically by the paver himself. No matter what filler is used, the joints should be made absolutely full, and preferably as nearly that as possible at the first pouring. If bituminous cement is used, it is poured hot; and if it is allowed to cool and soak away, leaving voids, it is not always possible to fill the joints completely, or to know even if they have been filled. With a Portland cement filler, some specifications require that the blocks shall be entirely covered with the grouting to a specified depth. This seems unnecessary, as the grouting will wear off unevenly, making the surface of the pavement rough, and not adding materially to its life. When a Portland cement filler is used it is of the greatest importance that all traffic should be kept off the pavement until the cement has thoroly set.

8. Recut Blocks

Description. For many years the granite blocks taken from a street when a new pavement was to be laid were not considered to be of any particular value for use in city streets; they were sold for use in freight terminals and similar locations where a first-class pavement was not required. About 1908, however, some of the granite block producers of New York City took up the question of recutting the old blocks and laying them in a new pavement. These old blocks were from 7 to 8 in in depth, and some of them 14 in long. The idea was to break them in two, in the center, and to use the new face as the head of the block. This would give a block from 5 to 6 in deep, if the original blocks were 10 and 12 in long. If necessary, the old head of the block could be dressed so that it would have a very good shape. In order to get the best results from work of this character a little more variation must be allowed in the specifications, and that is permissible, as generally this work is done on streets of light traffic. Success, too, depends to a great extent upon the character of the granite in the old blocks, as some will break much more easily than others. It is undoubtedly true, with the idea of the smaller granite blocks, that a great many of the old blocks can be utilized, and if recut as before described and laid on streets of moderate traffic, excellent results can be obtained.

The Bureau of Highways, Brooklyn, N. Y., has laid a considerable quantity of this pavement, and with satisfactory results; and the specifications for this pavement are as follows: "When the use of blocks recut from old granite blocks is permitted under the contract, such blocks shall comply with the specifications for quality as required for new blocks, and be of the following dimensions, not less than 6 nor more than 10 in long on top, not less than 3¼ nor more than 4½ in wide on top, and not less than 4¾ nor more than 5¼ in deep. The recut blocks shall be dressed in the manner specified for new blocks, except that the sides and ends shall be sufficiently smooth to permit of the blocks being laid with joints not exceeding ⅜ in in width

at the top and for 1 in downward therefrom, and not exceeding 1 in at any other part of the joint."

Borough of Manhattan, New York City. A contract was carried out in the Borough of Manhattan, in 1914, amounting to something over 5000 sq yd of recut blocks, the blocks being broken in two and laid with the newly broken side up, on a 1-in sand cushion. A portion of this pavement was filled with tar and another portion with cement grout, the object being to ascertain the difference in wear of the two methods. This pavement cost $1.45 per sq yd, not including the foundation.

Borough of the Bronx, New York City. Probably the first street laid of recut blocks was in the Borough of the Bronx in 1909. The specifications called for the blocks to be 6 to 12 in long, 3½ to 4½ in wide, and 5½ to 6½ in deep, and, as the work as a whole was an experiment to a certain extent, blocks 4¾ or even 5 in in width were used provided all courses were of the same width. The price bid for the work was $1.25 per sq yd for the granite laid. The joints were filled with cement grout, so that all the small inequalities of the blocks were filled. The result was a first-class pavement for light traffic streets and at a very small price. The contractor was paid, for making the blocks, $10 per thousand.

Philadelphia. More recently, a street in Philadelphia, containing over 10 000 sq yd, was laid of blocks reclipped at a cost, including the sand cushion, of $1.48 per sq yd, the old concrete being used. The specifications called for the blocks to be redressed, of dimensions 5 to 6 in deep, 5 to 7 in long, and 3½ to 5 in wide.

In Troy, N. Y., in 1913, a pavement of old blocks was relaid, but cut by a little different method. The blocks were practically of regulation size, and were first halved, and then quartered, so that they were from 7 to 9 in long, 4 to 5 in wide, and 4 to 5 in deep. These blocks were laid on a sand cushion, and grouted with Portland cement. The cost was $2.30 per sq yd including foundation, with maintenance for a period of 5 years. In this work it is stated that an excess of 25% of blocks was obtained over and above what was required for the street itself, and that the contractor was allowed $15 per thousand for them delivered within a radius of ½ mile from the place of cutting. The price for the standard pavements in Troy had been on an average $3.85 per sq yd.

The City of Newark, N. J., has probably laid more of this pavement than any other city. In 1914 it let contracts for 32 500 sq yd of recut blocks, with grouted joints, at an average cost of $2.50 per sq yd. In 1914, Howell (15) stated that the old blocks there ran from 10 to 14 in in length; that a block maker in a day of 8 hr could cut 175 blocks, making 350 small ones, and that the city sold the contractor the old blocks at $30 per thousand, which would make the smaller ones cost him $15 per thousand, including the cutting. The blocks ran 21 to the yard for the large size and 42 to the yard for the small size.

9. Specifications for Construction

The following specifications were adopted in 1916 by the Am. Soc. Mun. Imp. For sections covering physical properties of stone blocks see Art. 5. Specifications relative to the practice in several American and European cities pertaining to methods and materials employed in filling joints in stone block pavements will be found in Art. 7.

"**Sub-Foundation.** Any soft or spongy material below the subgrade, shall be replaced with sand, gravel or other material, as directed by the engineer, and thoroly rammed or rolled. When such extra fill exceeds 5 cu yd, payment will be made for the excess. Care shall be taken in excavating not to disturb the sub-foundation, except where necessary to remove the soft or spongy materials. The entire sub-foundation shall be compact and hard, and the contractor shall be required to ram or roll it thoroly with a roller satisfactory to the engineer.

"**Cement-Concrete Foundation.** After the sub-foundation has been prepared to the satisfaction of the engineer, a concrete foundation 6 in thick shall be laid thereon. The concrete shall conform to the Am. Soc. Mun. Imp. specifications for concrete for pavement foundation. The grading and sub-foundation shall be completed at least 50 ft in advance of the laying of concrete.

"**Cushion Course.** On the concrete base shall be spread a layer, averaging 1 in in

depth, of clean, coarse, dry sand, free from all gravel exceeding ¼ in in size. Upon this sand bed the blocks shall be laid in courses at right angles to the line of the street, and in a straight line from curb to curb, except in special cases, when they shall be laid at such an angle as may be directed by the engineer. The blocks shall be laid as closely as possible, each block touching the adjoining one on sides and ends, and in courses of uniform width. All joints shall be broken with a lap of at least 3 in. The blocks shall not be laid more than 25 ft in advance of the ramming.

"Ramming. After the blocks are laid, they shall be rammed to a solid bearing; the joints shall be adjusted; all unsatisfactory blocks shall be taken out with tongs, and all low blocks shall be raised by adding to the bed. The whole pavement shall then be rammed to an even and true surface. Pinch bars shall not be used except by special permission of the engineer and no sand shall be placed in the joint except when mixed with the bituminous filler specified hereafter.

"Filling Joints. The following specifications A, B, or C, shall govern the use of Tar Pitch (A), Asphalt (B), or Cement Grout (C), depending upon the kind of filler to be used in the joints.

"A. Tar Pitch Filler. The joint filler used shall be the paving pitch hereafter described thoroly mixed with as much hot, dry sand, as the pitch will carry, but in no case shall the volume of the sand exceed the volume of the pitch. The sand shall be fine and clean, and all of it shall pass a 20-mesh sieve. It shall be heated to a temperature of not less than 149° C (300° F) nor more than 205° C (400° F) and shall be between these limits when mixed with the paving pitch. The paving pitch shall be heated in kettles properly equipped with an approved thermometer, which shall register the temperature of the pitch. The mixture shall be flushed on the surface of the blocks and pushed into the joints with suitable tools, reflushing or repouring if necessary, until the joints remain permanently filled flush with the surface of the pavement. As little as possible of the mixture shall be left on the surface.

"The tar pitch shall comply with the following requirements:

1. It shall have a specific gravity between 1.23 and 1.33 at 15.5° C (60° F).
2. It shall have a melting point between 46° and 57° C (115° and 135° F), determined by the cube method in water.
3. It shall contain not less than 20% nor more than 35% of free carbon insoluble in hot benzol or chloroform.
4. It shall contain not more than 0.5% of inorganic matter.
5. It shall be free from water.
6. It shall have a ductility of not less than 60 cm at 25° C (77° F).

"The tar pitch shall be used on the work at a temperature of not less than 121° C (250° F) and shall at no time be heated above 163° C (325° F). It shall be delivered where directed by the engineer in time to allow for examination and analysis. In applying the filler, care shall be taken that the pavers are closely followed by the filler gang, and in no case shall the paving be left over night, or when work is stopped, without the filling of the joints being completed. In case rain stops the filler gang before its work is finished, the joints shall be protected by the use of tarpaulins, or other means, to keep out water. Under no circumstances shall the filler be poured into wet joints.

"B. Asphalt Filler. The joint filler used shall be the asphalt cement hereafter described, thoroly mixed with as much hot, dry sand as the cement will carry, but in no case shall the volume of the sand exceed the volume of the cement. The sand shall be fine and clean, and all of it shall pass a 20-mesh sieve. It shall be heated to a temperature of not less than 149° C (300° F) nor more than 205° C (400° F) and shall be between these limits when mixed with the cement. The asphalt cement shall be heated in kettles properly equipped with an approved thermometer, which shall register the temperature of the cement. The mixture shall be flushed on the surface of the blocks and pushed into the joints with suitable tools, reflushing or repouring if necessary, so that the joints remain permanently filled flush with the surface of the pavement. As little as possible of the mixture shall be left on the surface.

"The asphalt paving cement shall be obtained by the distillation of an asphaltic petroleum at a temperature not exceeding 372° C (700° F), and shall comply with the following requirements:

1. It shall be homogeneous.

2. Its melting point shall not be less than 54° C (180° F) nor more than 63° C (145° F).
3. Its solubility in carbon tetrachloride shall not be less than 98.5%.
4. Its penetration at 25° C (77° F) shall not be less than 60 nor more than 100, the penetration test being made with a No. 2 needle for 5 sec under a load of 100 g and the penetration at 38° C (100° F) shall not exceed three times its penetration at 25° C (77° F), the condition of time and load being as above established. The Contractor, before beginning work, shall obtain from the Engineer a statement in writing as to the penetration desired for any particular contract and a variation of not greater than ten points either way from this penetration will be permitted.
5. Its ductility at 25° C (77° F) shall not be less than 40 cm, the rate of elongation being 5 cm per min.
6. It shall not lose more than 3% by volatilization when maintained at a temperature of 163° C (325° F) for 5 hr, nor shall the penetration of the residue, after such heating, be less than one-half the original penetration.

"The asphalt filler shall be used on the work at a temperature of not less than 135° C (275° F) and shall at no time be heated above 177° C (350° F). It shall be delivered where directed by the engineer in time to allow for examination and analysis. In applying the filler, care shall be taken that the pavers are closely followed by the filler gang, and in no case shall the paving be left over night, or when work is stopped, without the filling of the joints being completed. In case rain stops the filler gang before its work is finished, the joints shall be protected by tarpaulins or other means, so as to keep out water. Under no circumstances shall the filler be poured into wet joints.

"C. Cement Grout Filler. After the pavement has been brought to a uniform surface, Portland cement grout shall be poured into the joints until it appears on the surface. The grout shall be broomed or scraped into the joints if necessary to fill the same, and the operation shall be repeated as the grout settles and before the initial set has taken place, until the joints are thoroly filled flush with the surface of the blocks. Immediately after this the entire pavement shall be broomed to a smooth surface. The blocks shall be wetted immediately before applying the grout.

"The cement grout shall be composed of one part of Portland cement and one part of clean, sharp sand. The cement and sand shall be thoroly mixed dry and only enough clean fresh water shall be added to make a grout which will flow to the bottom of the joints.

"The grout shall be machine mixed in a batch mixer approved by the engineer and shall be applied to the joints before the ingredients have separated. Particular attention is called to the importance of ascertaining the proportional amount of water to be used with the mixture of different kinds of cement and sand to give the best results, and when the most advantageous proportions have been ascertained, these shall be used.

"After the grouting is completed, and a sufficient time for hardening has elapsed so that a coating of sand will not absorb moisture from the cement mixture, ½ in of sand shall be spread over the whole surface and shall be kept damp until the street is opened for traffic. After the grouting is completed the street shall be kept closed and no carting or traffic allowed on any part of the grouted pavement until at least 7 days have elapsed. Should the bond between the blocks become broken, before the work is accepted, such defective work shall be regrouted or relaid and again barricaded, as previously described."

10. Construction Cost Data

The cost of construction work of any character will vary according to localities. Prices of labor and material are always different in different places, but if the correct quantities of labor and material are given for any construction, it is a simple matter for any engineer to apply the costs of these two items to his location; so that in presenting the cost of stone block or other pavements, it is intended to be accurate as regards the quantity of work done and the amount of material consumed for any locality, and to be accurate as to prices of labor and material where the cost of the work is given.

Borough of Brooklyn, New York City. The following is the organization actually employed in constructing granite block pavement in 1914.

Cement-Concrete Foundation

Labor		Materials per Cu Yd of Concrete			
Gang	Per Day	Item	Quantity	Price per Unit	Cost
1 foreman	$5.00	Cement..	1 bbl	$1.30	$1.300
2 men wheeling sand	4.00	Sand.....	0.44 cu yd	0.90	0.396
1 cement man	2.00	Broken			
4 blend mixers	8.00	stone...	0.88 cu yd	1.85	1.628
2 blend shovelers	4.00				
5 stone shovelers	10.00	Cost per cubic yard			$3.324
1 stone trimmer	2.00				
2 plank men	4.00	Material cost per cu yd			$3.324
4 concrete wheelers	8.00	Labor cost per cu yd			0.670
4 concrete rakers	8.00				
2 concrete rammers	4.00	Total cost per cu yd			$3.994
1 concrete broomer	2.00				
1 man at tail of mixer	2.00	Total cost per sq yd for 6 in			
3 fine graders	6.00	foundation			$0.666
1 engineer	4.75				
Use of mixer and team to haul	10.00				
	$83.75	Total 750 sq yd (125 cu yd) @ 11.2 cents.			
Total cost per cu yd based on laying 125 cu yd per day					$0.67

Granite Block Paving

Labor		Materials per Square Yard Granite Paved			
Gang	Per Day	Item	Quantity	Price per Unit	Cost
1 foreman	$5.00	Granite....	28 per sq yd	$2.00 sq yd	$2.00
7 pavers at $5.00	35.00	Pitch.....	20 lbs	15.00 ton	0.15
3 rammers at $4.00	12.00	Gravel....	0.04 cu yd	2.00 cu yd	0.08
7 pourers at $2.00	14.00	Sand......	0.03 cu yd	1.00 cu yd	0.03
8 laborers at $2.00	16.00				$2.26
	$82.00	Cost of materials per sq yd			$2.26
Total cost per sq yd based on laying 455 sq yd per day		Cost of labor per sq yd			$0.18
	$0.18	Total cost per sq yd			$2.44

Hence, as the concrete costs $0.666 per sq yd and the granite $2.440 per sq yd, the total cost per sq yd with 5% of the sum of the above items added for incidentals, $0.155, will be $3.261. The average price paid to contractors in 1914 was $3.53 per sq yd.

Minneapolis, Minn. The following is the organization used, the work being done by the city:

Grouted Stone Block Paving

1 superintendent, part time	$1.00
1 timekeeper, part time	0.50
1 foreman, per day	4.50
6 pavers at $3.50 per day	21.00
1 rammer, per day	3.00
1 sweeper, per day	2.50
6 tenders at $2.50 per day	15.00
1 water boy, per day	1.50
4 men grouting at $2.50 per day	10.00
	$59.00

This gang will lay 330 sq yd per day at $0.179 per sq yd. Stone costs $1.75 per sq yd. making a total of $1.929 per sq yd, not including foundation.

BALTIMORE. In 1914 (13 b), a recut block pavement cost per square yard as follows:

Breaking up old pavement	$0.09
Recutting old blocks	1.00
Hauling, laying and grouting	0.71
Total	$1.80

The average cost of new blocks laid was $2.80; thus there was saved $1 per sq yd.

Schenectady, N. Y. The following figures give the cost in detail for laying a recut granite block pavement in 1913, containing 2587 sq yd.

	Total		Per Sq Yd	
Labor, ripping up asphalt and concrete	$115.28		$0.0445	
Team hire, hauling asphalt and concrete	40.27		0.0156	
Labor, ripping up old granite blocks	78.76		0.0305	
Labor, regulating and grading subgrade	107.81		0.0417	
Team hire, hauling materials from subgrade	62.41		0.0241	
		$404.53		$0.1564
1 : 3 : 6 Cement-Concrete Foundation 4 in Thick	Total		Per Sq Yd	
Labor, mixing and laying concrete foundation	$308.27		$0.1192	
Material, cement delivered on job	263.35		0.1018	
Material, sand delivered on job	71.08		0.0275	
Material, stone delivered on job	216.22		0.0835	
		$858.92		$0.3320
1 : 3 Cement Mortar Bed, Thin	Total		Per Sq Yd	
Labor, mixing and placing mortar bed	$190.80		$0.0738	
Material, cement on job	224.42		0.0868	
Material, sand on job	62.80		0.0242	
		$478.02		$0.1848
Breaking, Dressing and Laying Blocks	Total		Per Sq Yd	
Labor, breaking and dressing granite	$1910.57		$0.7385	
Labor, sharpening and making tools	129.38		0.0501	
Material, sharpening and making tools	15.00		0.0058	
Team hire, shifting blocks	15.30		0.0059	
Labor, handling blocks to pavers	102.38		0.0396	
Labor, laying blocks	464.77		0.1796	
Labor, ramming blocks	16.98		0.0065	
		$2654.38		$1.0260
1 : 2 Cement Grout Joints and Surface	Total		Per Sq Yd	
Labor, mixing and placing grout	$120.66		$0.0466	
Material, cement on job	182.85		0.0707	
Material, sand on job	27.55		0.0106	
		$331.06		$0.1279
Overhead Charges	Total		Per Sq Yd	
Labor, foreman, assistant foreman, etc	$211.94		$0.0819	
Labor, watchman	142.87		0.0552	
		$354.81		$0.1371
Extra Work				
Repairs to side walks, etc		$111.18		$0.0430
Grand total		$5192.90		$2.0072

Unit prices: foremen, per day, $4; assistant foremen, per day, $3.50; block cutters, per day, $5; pavers, per day, $5; laborers and watchmen, per day, $2.25; teams, wagon and driver, per day, $5; horse, wagon and driver, per day, $4; Portland cement bbl f.o.b. cars, $1.24; sand, ton, f.o.b. cars, $0.25; crushed stone, 1½ in, ton, f.o.b. job, $1.75; crushed stone ¾ in, ton, f.o.b. sidetrack, $1.20.

The old blocks were 8 in deep and ranged from 12 to 16 in in length. The 16-in blocks were broken into four parts, making four blocks 4 by 4 by 8 in. The 12-in blocks were cut into four parts by splitting the blocks lengthwise, making two blocks 12 in long and 4 in deep, and these were broken in the middle, each making two blocks 4 in deep and 6 in long; so that a 4 by 12 in block would make four new blocks each 4 by 6 in, and a 4 by 16 in block would make four blocks 4 by 4 in on top and 8 in deep. In other words, each 12-in block would have a surface of 48 sq in, while the four new ones would have a surface of 96 sq in; each 16-in block would have a surface of 64 sq in; while the four new 4 by 8 in blocks would have a surface of 128 sq in.

The following figures are for another job in Schenectady containing 4189 sq yd covering, removing and disposing of old asphalt blocks, repairing foundation, recutting old 4 by 8 by 12 in blocks to 4 by 4 by 6 in blocks, laying in 1 : 4 mortar bed, and applying 1 : 2 cement grout and surface plaster.

	Cost Per Sq Yd
Grading and removing old materials	$0.1212
Patching up old concrete base	0.0443
Mortar bed	0.2033
Breaking, dressing and laying blocks	1.0339
Grouting joints and surface	0.1483
Overhead charges	0.1550
Extra work	0.0062
Total	$1.7122

Newark, N. J. The following are the figures given by Howell, (15) as the cost per sq yd for a pavement laid with recut blocks:

Blocks, 21 per sq yd at $0.03	$0.63
Paid clippers for work	0.53
Laying and handling	0.20
Sand	0.05
Concrete	0.65
Grading	0.10
Hauling	0.10
Grouting	0.12
Total per sq yd	$2.38

11. Durax and Kleinpflaster

Description. Small stone block pavements known as Durax and Kleinpflaster have been laid to a considerable extent in Europe, the former name being used in England and the latter in Germany. The principal feature of the pavements is the small irregular size of the blocks, approximating cubes 2½ to 4 in in size. At the present time practically all blocks are made with specially designed machines. An efficient operator at one machine can make on an average 2400 blocks in a 10-hr day. They are sufficiently irregular both in size and shape to permit them to be laid in arcs of circles of comparatively small radii and so that the joints will not be excessively large. By laying the courses in circular arcs practically none of the joints are parallel to any line of traffic. In Europe these blocks have been used to a great extent in resurfacing the broken stone roads where the traffic is too heavy for the macadam and to some extent on city streets. They have been used to a slight extent in pavements in some southern cities in the United States.

Table IV.—Character and Cost of Stone Block Pavements in 1915 in Several Cities

From *Engineering and Contracting*, April 5, 1916

City	Sq Yd	Price* per Sq Yd	Guarantee Years	Kind of Filler	Concrete Foundation: Thickness In	Concrete Foundation: Proportions
Boston, Mass......	30 167	$3.25	...	Gravel	6	1 : 3 : 7
Lowell, Mass......	20 630	3.75	...	Cement grout	6	1 : 4 : 10
Worcester, Mass....	16 612	3.24	...	Cement grout	5	1 : 3 : 6
Hartford, Conn....	1 096	3.56†	1	Cement grout	6	1 : 3 : 6
Providence, R. I....	20 987	3.76†	...	Cement grout	6	1 : 3 : 6
Albany, N. Y......	19 117	2.17	5	Cement grout	6	1 : 3 : 6
Amsterdam, N. Y...	6 807	3.70	1	Pitch	6	1 : 3 : 6
Borough of Manhattan, N. Y. City	66 473	3.74	1	Asphalt	6	1 : 3 : 6
Borough of Brooklyn, N. Y. City...	108 840	3.18‡	1	Pitch and Sand	6	1 : 3 : 6
Camden, N. J......	35 179	2.85	1	Cement grout	6	1 : 3 : 6
Pittsburgh, Pa.....	15 640	2.80	1	Cement grout	6	1 : 3 : 6
Baltimore, Md.....	61 893	3.30†	5	Bituminous	6	1 : 3 : 6
Toledo, Ohio.......	2 978	3.40†	5	Asphalt	6	1 : 3½ : 6
Chicago, Ill........	60 828	3.83†	5	Pitch	6	1 : 3 : 6
Milwaukee, Wis....	25 173	2.90†	...	Cement grout	6	1 : 3 : 6
St. Paul, Minn.....	16 142	3.04	...	Cement grout	5	1 : 2½ : 5
Kansas City, Mo...	14 435	3.15	5	Cement grout	6	1 : 3 : 6
Sioux Falls, S. D...	1 924	3.59	1	Asphalt	5	1 : 2½ : 5
Petersburg, Va.....	4 000	3.07†	5	Asphalt	5	1 : 3 : 6
Nashville, Tenn....	19 236	2.78	...	Cement grout	6	1 : 3 : 6
Portland, Ore......	3 346	3.15†	...	Cement grout	6	1 : 3 : 6

*Price covers pavement, foundation, and shaping subgrade.
†Does not include shaping subgrade.
‡Includes taking up old pavement.

Construction and Cost Data. Germany (9). The Kleinpflaster stone block pavement on the Döberitzer Heerstrasse between Berlin and Charlottenburg is composed of a series of three stone course arcs averaging about 12 in in overall width between which Kleinpflaster cubes are laid diagonally. The cords of the rings average 7 ft and the middle ordinates 16 in. The size of the Kleinpflaster cubes vary in surface dimensions from 2½ by 2½ in to 3½ by 4 in. The widths of the joints vary from ¼ to ⅓ in. It is reported that this pavement was laid upon a gravel foundation with gravel filled joints. The width of the center drive of this famous boulevard, paved as above described, is 37 ft.

England. Victoria Road, Eltham (9). The current practice of constructing a Durax stone block pavement is typified by the method used in laying the Durax pavement on Victoria Road in Eltham in 1913. On a prepared macadam foundation, tarred sand was laid to such a depth that, after the Durax cubes were rammed, the depth of sand was between ¼ and ½ in. The alignment of the blocks and the number of arcs in a transverse section were controlled by iron pegs driven into the macadam foundation prior to the laying of the blocks. Strings stretched between these iron pegs served as guides for the placing of the stones from which adjacent arcs sprung. The largest cubes were laid at the center of the arcs and adjacent thereto, while the smallest cubes were laid near the springing lines. The arcs were so laid that the cords averaged 3 ft 6 in and the middle ordinate varied between 9 and 10 in. After the joints of the blocks were filled with clean stone chips, the blocks were well rammed. The final operation consisted in pouring the joints with hot pitch and covering the surface with gravel. The cost of this Durax pavement was 8 shillings ($1.95) per yd

super with foundation, the work being carried out by contractors under a 5-year maintenance contract. The blocks used in the pavement were furnished by the Durax Dustless Roads, Limited. This company manufactures these blocks in three grades, having the following limiting edge dimensions: 7 to 9 cm (2¾ to 3½ in), 8 to 10 cm (3¼ to 4 in); and 10 to 12 cm (4 to 4¾ in). One grade is furnished for the construction of a given pavement.

London Folkestone Road, Sidcup, Kent County (21). The granite cubes used were obtained 50% from the Durax Dustless Roads Company's Swedish quarries at Rixe, the remainder from the Company's Enderby quarry near Leicester. The size of the cubes was 7 to 9 cm (2¾ to 3½ in), giving a finished depth of paving of about 3¼ in. The grouting mixture was composed of coal tar pitch, tempered with creosote oil or tar, into which was stirred about 30% of fine, dried sand. The existing macadam was scarified and removed and the foundation thoroly consolidated by wetting and rolling. On this prepared foundation a layer of tarred limestone or slag chippings was spread to a thickness of ¾ in, and the cubes laid on this in intersecting segmental courses, the paving being afterwards thoroly consolidated by hand ramming. The grouting mixture was poured on the surface in a boiling state and forced into the interstices with a rubber squeegee, the whole surface being then covered with hot chippings applied before the grouting had solidified. This was consolidated by hand ramming and steam rolling. The report to the Board also states that there had been no repairs on this section from the date of completion, July, 1911, up to Nov., 1912. The original cost is given as 7 shillings 6 pence ($1.80). The traffic census between Aug. 15 and 21, 1912 showed an average daily traffic, 6.00 A. M. to 6.00 A. M., of 750 cycles, 638 motor vehicles and trailers, and 386 horse-drawn vehicles, giving an average weight in tons per yard width of carriageway of 506, the total width of carriageway being 21 ft.

Specifications. The following abstracts from specifications are typical of the practice of constructing Durax pavements in the United States:

The Durax cubes, which shall be of medium grained granite, showing an even distribution of constituent materials, shall be of uniform quality and texture, without seams, scales or discoloration showing disintegration, free from an excess of mica or feldspar, and equal in every respect to the sample in the office of the Engineer. The granite shall be such as will give about 30 000 lb per sq in crushing strength, combined with a uniform structure and toughness of 12 as determined by the method employed by the Dept. of Agr. of the U. S. O. P. R. from samples taken directly from quarry. Durax cubes shall have six irregular, approximately square surfaces, the edges of which shall measure not more than 4 and not less than 2¾ in provided the blocks used on any one city block shall not vary more than ¾ in in size, that is, either from 2¾ to 3½ in, or from 3¼ to 4 in.

On the concrete base shall be laid 1½ in of a cushion composed of clean sand and Portland cement in the ratio of 2 to 1. This cushion shall be made true with the use of a templet and shall be compacted by rolling to the satisfaction of the Engineer. On this cushion the cubes shall be laid carefully and close together taking pains to break joints as much as possible; the said cubes shall be laid in the form of an arc, the break in the arc to be 5 ft in width or such other width as directed by the Engineer. After the cubes are laid, they shall be thoroly rolled and made true to the crown of the street with a roller weighing not less than 5 tons, after which the surface of the Durax cubes shall be thoroly sprinkled several times sufficient to moisten the cushion after which the same shall be thoroly grouted with grout composed of clean sand and Portland cement in the ratio of 1 to 1. The surface of the pavement shall then be covered with sand and kept moist for a period of 1 week. Provided the Engineer so directs instead of filling the joints with grout, the same shall be filled with hot asphalt and hot sand mixed together in such proportions as may be required by the Engineer. If an asphalt filler is used the joints shall be dry before pouring and the asphalt used in the filler shall be an asphalt which will not become brittle at −18° C (0° F) nor flow at 49° C (120° F) and shall be waterproof, free from water or decomposition matter; shall adhere to the paving stones and shall remain ductile and pliable at all climatic temperatures to which it may be subject in actual use. The asphalt shall be mixed by volume with 50% hot sheet-asphalt sand. After an asphalt filler has been applied, the entire surface shall be covered with a coarse sand which shall be swept over the surface and joints.

12. Stone Trackways

Trackways have been built, both in this country and abroad, of stone slabs, brick, concrete blocks, steel shapes, and other materials. Stone trackways were used on one of the old toll roads in New York State as early as 1831. The slabs, which measured 24 in in width by 4 in in thickness, were laid with a gauge which would accommodate the vehicles. The space between them was paved with cobblestone. Trackways of rectangular stone blocks, averaging 12 in wide, 6 in thick, and of varying lengths, have been used in some cities of England and Scotland on steep hills or where the traffic is exceptionally heavy. These trackways, locally called " wheelers," are laid in many parts of Great Britain, but mostly in Liverpool and Glasgow. They are laid on streets with heavy grades, so as to reduce the traction. In Glasgow, in 1913, there were 10.75 miles of these " wheelers." The stones of which they are made vary in size from 10 to 15 in in width and from 6 to 8 in in depth, according to conditions. They cost about $1.40 per running ft. These " wheelers " too are often seen in the rural sections of England, where they are laid on steep grades, both in order to reduce the wear and tear of heavy loads and also to reduce traction, as in the cities. Granite trackways, made of slabs 2 ft wide, 1 ft thick, spaced 4 ft apart on centers, are used in several cities in Switzerland.

13. Crosswalks

In America it used to be customary to lay crosswalks at each street intersection in all stone block pavements to accommodate pedestrians. This was more necessary with the old style pavement than with the modern blocks, and the practice may be discontinued if the improved form of blocks is generally adopted. The character of the stone in the crosswalks should be the same as that in the pavement, so that the wear may be uniform upon both.

The Bureau of Highways, Brooklyn, N. Y., specifications for crosswalks, say: "They shall be 18 in wide, of a uniform thickness, not less than 6 nor more than 8 in in depth, and from 3½ to 8 ft in length, except that in special cases between railroad tracks they may be of such dimensions as may be approved by the Chief Engineer of the Bureau of Highways.

"The top shall be dressed to a surface not varying in evenness more than ¼ in. The sides and ends shall be dressed square down and the latter cut to a transverse bevel of 6 in in width, or to such other bevel as may be directed, and the jointing from top to bottom shall give joints not greater than ¼ in.

"The bridge-stones shall be laid in parallel courses separated by granite blocks, and shall be well and firmly bedded on a layer of sand spread on the foundation as prepared for the pavement. The transverse joints shall be broken by a lap of at least 1 ft, and be so laid as not to be parallel to vehicular traffic.

European Practice. In Europe in some cities crosswalks are provided, and in others specially dressed blocks are laid where the crosswalks would naturally be placed.

The London specifications in this respect say: "The crossings shall be formed of 4 by 7 in specially dressed Aberdeen granite setts, and two rows of 12 by 6 in flat kerbs laid on a bed of Portland cement-concrete at least 6 in thick, the surface of both concrete and granite being cambered transversely as directed by the Engineer. The flat kerbs and setts shall be laid in straight, close jointed, and properly bonded courses, all the joints being solidly grouted with Portland cement and Thames sand, as before described, well rammed, back rammed, finished to a true surface, and covered with a top dressing of fine shingle."

The Liverpool specifications say: "The crossings shall consist of three rows of 16 by 8-in granite crossing stones, and the remaining space shall be paved on each

side of the crossing stones, to the full width of the footway, in a similar manner to the carriageway. The crossing stones shall be of granite of a quality to be approved by the City Engineer, dressed perfectly true, and out of winding on the face; the sides and joints to be perfectly square and accurately dressed thruout their entire depth; the stones to be bedded in cement-concrete, the joints to be filled with shingle and grouted in a similar manner to the paving. A triangular groove 1 in wide by ¾ in deep to be formed along the upper surface of each stone. No stone to be less than 3 ft in length."

Glasgow requires for its street crossings all blocks dressed as follows: "Each crossing sett shall be axed on the top, jointed on the sides and ends, dressed on the bed, shall be level on the top and bed, and have sides and ends parallel and square; the axing, jointing, and dressing shall be equal to the sample to be seen in the Office of Public Works. Setts of each class shall be truly gauged. No variation in width or depth greater than ¼ in over or under the sizes specified on orders will be allowed. All setts must be free from cracks and flaws. Setts with bulges or hollows will not be accepted."

It would seem that possibly as good results could be obtained by having stones in the line of the crossings specially dressed as by the use of large, flat stones. The average price for crosswalks in Brooklyn, N. Y., is $0.75 per sq ft or $6.75 per sq yd, while the price for the blocks, Grade 1, was in 1914, $2.84 per sq yd. This would allow a difference of $3.91 per sq yd, which would considerably more than pay for the extra dressing of the blocks that would be required to make a smooth surface.

MAINTENANCE

14. Maintenance Methods

The cost of a pavement in any city, especially the cities of America, is difficult to obtain. It is questionable, too, of how much value this information would be, as in most instances American cities do not have money enough to keep their pavements in good repair, and too often the information would be the amount of money paid out for repair work rather than the actual cost of necessary repairs. Then, too, the character of the street upon which the pavement is laid makes a great difference. For instance, it would be a simple matter in any city to lay on a selected street a granite pavement which would last 50 years and would require practically no work for repairs during the entire time, while, on the other hand, a pavement could be laid on a heavy traffic street where it would only last from 10 to 15 years, and then only after heavy and constant repair.

European cities, as a rule, have stone block pavements of some form, except where streets have been repaved in recent years, even on residence streets. In 1913 a stone pavement on the principal street of Berne, Switzerland, which had been laid 25 or 30 years at least, appeared, considering the traffic and other surrounding conditions, to have an additional life of 25 years. The street was solidly built up, and there was little prospect of any change in conditions, so that the pavement would probably be undisturbed for years.

It is a fact, however, that it is the wisest of economies for any city to keep all its pavements, stone block as well as others, in the best of repair. The life of a stone pavement will depend entirely upon traffic, and the better its condition is, the less will be the effect of that traffic. Organized gangs should be kept constantly employed in going over the stone block pavements to keep them in good condition.

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SECTION 20
BRICK PAVEMENTS

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GENERAL DATA

1. Historical Development

Brick Pavements, in the sense that they are highway surfacings laid with artificial blocks hardened by heat and made from shales or other mixtures of clay and sand, are of considerable antiquity. The Romans laid such pavements, where the brick or tiles were superficially 18 by 12 in. Holland, about 1700, was probably the first of modern nations to use brick similar to those now in use for pavements. Byrne (5) states that " the first brick pavement laid in the United States was in Charlestown, W. Va., 1872." Eldridge (29) gives credit to Monmouth Township, Warren County, Ill., for "being the first in this country to make experiments in the building of country roads with brick" in 1892. The brick used in Charlestown, W. Va. (10), in 1870 were side cut, repressed, hard burned building brick of high density and absorbing 4.5% on soaking 24 hr. Bloomington, Ill., and St. Louis also used brick between 1875 and 1882, but the pavements were unsatisfactory and no further effort was made to use brick until 1895. Wheeling, W. Va., put down an impure, fire clay paving brick in 1883 that was so successful as to make this one of the important pioneers of the paving brick industry from the confidence so inspired; some of these brick are still in use altho most of them were renewed after 2 years. Decatur, Ill., also put down a vitrified brick this same year (1883) that was made from a glacial clay, and this was still in use in 1909. The year 1885 witnessed the first substantial increase in the use of vitrified brick, as during that

year it was laid at Columbus, Zanesville and Steubenville, Ohio, and Peoria, Ill. By 1904, the importance of vitrified brick pavements had reached such a point that the organization of their manufacturers under the name of the "National Paving Brick Manufacturers Association" was had, and since that event, the progress in both the manufacture and use of vitrified brick for paving road and street surfaces has been rapid and considerable. For detailed historical data concerning brick pavements, see (30c).

Vitrified Brick. The earlier work was mostly of unvitrified brick similar to those used for ordinary building purposes, except that in most cases the effort was made to select the harder burned brick for pavements. In some cases, where they were readily available, more especially perhaps abroad, slag and scoria brick were used. Since the development of the vitrified brick, the use of unvitrified brick has been abandoned, and all modern brick pavements are laid with vitrified or slag brick. As a matter of fact, the term vitrified is misapplied, as the brick are not converted into glass by heat. Vitrification is approached but not reached in the manufacture, and annealing then takes place so as to produce a brick thoroly compact, hard, and tough, but not brittle. The term, however, has acquired such general use that it will probably continue as a means of differentiating brick so made, and perhaps really vitrified superficially, from those simply hard burned for ordinary building purposes.

The Development of the Use of Slag Brick Abroad has been more rapid than in the United States, largely due to the fact that the manufacture of such brick in this country is extremely limited, and the importation of the foreign block has, in most cases, been so expensive as to preclude their use in spite of their advantages in some particulars. In Canada, where their cost is approximately the same as that of the vitrified clay and shale brick, the use of the slag brick is relatively much larger. Their manufacture and use in the United States is now on the increase.

The Use of Brick Pavements seems to be on the increase, especially in the case of roads. Until very recently practically all of the brick pavements laid were on city streets, but their extension to many country roads has occurred since 1910. Their success for road surfacing has been considerable in most respects, except possibly as regards the economy factor. In some cases at least, they have not been successful from this point of view, in that their cost to date has been greater than need have been incurred under the local conditions or for satisfaction. Undoubtedly in some of these cases, however, the change of local conditions taking place to produce more severe conditions will, if the proper maintenance is accorded these pavements, ultimately show that the selection of the brick pavement in many of these instances was wise from the point of view of economy. See (56).

2. Characteristics

Cheapness. While an average cost per square yard of a vitrified brick pavement on a cement-concrete base may be approximately and conveniently taken at $2, it may often, because of local conditions, be less than this. The omission of the concrete base and the utilization of the local foundation material, which may be proper under certain local conditions such as suitable materials and light traffic, may reduce the cost per square yard to as low as $1.25. The greater availability of brick for the surfacing, when the availability and propriety of other surfacings are considered under the same conditions, may show the cost of the brick pavement to be a favorable figure beside the cost of the other surfacings being

considered. On the other hand, it frequently happens that the first cost of brick pavements will be considerably more than $2 per sq yd and that the first cost of other suitable pavements from readily available materials will be at the same time much less than this figure. In such instances, the selection of the brick pavement must be justified by circumstances which will offset their higher first cost. See (16).

The Maintenance Cost, being made up partly by the interest on the first cost, will be affected by economy in the latter. The future maintenance cost, that is, the actual cost of making repairs to the pavement, resulting from the amount of traffic the pavement gets and its ability to resist the strains of such traffic, will depend upon the propriety with which the selection of the pavement is made for the local conditions and the character and efficiency of the maintenance accorded the pavement. Assuming that the selection of a brick pavement in any instance is proper, and that the character and efficiency of the actual maintenance is good, it is claimed that the maintenance cost of brick pavements is low. It has been claimed that it is practically nil, but this claim is an exaggeration. Necessity for repairs invariably arises even tho the intervening periods may seem relatively long. When these repairs have to be made, the cost must be distributed over the period. The length of this period is affected by the character of the construction and the amount of traffic. With extremely uniform brick and proper workmanship, a much greater evenness of wear and absence of broken brick or depressions in the pavement relieves the necessity for repairs to a much greater extent than in cases where uniformity of brick is lacking and where proper joint filling and good workmanship generally are deficient. The difficulties of securing uniform brick and proper workmanship in the construction of the pavement are not inconsiderable, and are perhaps greater than in the cases of some other competing pavements.

Durability is the ease of making and infrequency of repairs. It is generally fairly high where brick pavements have been properly selected for local conditions. Ease of repair to brick pavements may be greater than in the cases of some other pavements because no special plant is usually required for the prompt correction of minor defects. For instance, the repairing of a plumber's cut in a brick pavement can be quite efficiently done without the use of machinery, whereas in the case of a bituminous concrete or sheet-asphalt pavement, it is questionable if the repairs could be successfully made in the absence of a heating and mixing plant. The strength and resistance to wear of brick pavements is limited, and they will not satisfactorily endure under the heaviest traffic, such as frequently prevails in large cities especially along the docks or freight yards, even when the pavements are laid in the best possible manner from the toughest selected brick.

Resistance to Traction of a brick pavement is relatively light. The following table will give an idea of the relative values of different pavements in this respect:

Character of Surfacing	Resistance in Pounds per Ton	Authority
Sheet-asphalt	17	Gordon
Brick	26	Eldridge
Granite block	35 to 132	MacNeil and Rumford
Gravel	75 to 320	Bevan
Macadam	30 to 160	Morin and Gordon

The figures for bituminous concrete and for cement-concrete surfacings are not available. Those for bituminous concrete would probably be somewhat higher than for sheet-asphalt and might be considerably higher, as would also be the case with the sheet-asphalt itself during periods when the bituminous cement became soft under heat. Brick pavements would not be so affected. The figures for cement-concrete would probably be higher than those for sheet-asphalt or brick, but probably less than those for bituminous concrete when conditions are most unfavorable for the latter.

Non-Slipperiness. As the slipperiness of a pavement depends not only upon its character but upon the condition of the surfacing, comparisons of slipperiness can only be made under the assumption that conditions of the surface, such as are affected by the cleanliness of the pavement for instance, are the same. These surface conditions are further modified by weather and climatic conditions. Cement grouted brick pavements are smoother than those with bituminous filled joints, and consequently to some extent offer less foothold for horses. This is especially true when the dirtiness of the two surfaces is the same, because the depressions in the bituminous filled joints do not permit the slipping of the horses' shoes to the extent that will occur on the smoother surface of the cement grouted pavement. The cement grouted brick pavements, however, are not generally as slippery, especially in cold weather, as bituminous surfaces, and the latter seem to become slippery more readily in the presence of adventitious products than do even the cement grouted brick pavements.

Sanitariness. Brick pavements, if kept clean, are highly sanitary, because of their imperviousness. In the case of hillside brick or of pavements with bituminous joints, where depressions along the joint lines exist to a greater or less extent, decomposing matter may be held for considerable periods and such pavements are not as sanitary as the cement grouted pavements where the surface is smoother. On the other hand, when the regular cleaning of the pavements is defective for any reason, there are no qualities inherent in the brick pavement, such as do exist to a certain extent in the bituminous pavements, which interfere somewhat with the development of bacteria. Many bituminous materials have a considerable effect toward preventing or interrupting the growth of bacteria in the organic matter reaching their surfaces, and in this way tend to increase the sanitariness of their immediate surroundings. With both cement grouted brick pavements and bituminous pavements where the surface is quite smooth, the dustiness, which is a consideration under the head of sanitariness, may not be seriously objectionable even tho maintenance conditions are not ideal. In these cases the traffic itself may keep extraneous matter so swept to the sides of the roadway as to prevent its becoming objectionable by its presence. With the rougher surface brick pavements, such as those with bituminous joints or of hillside block, the conditions as to dustiness in the event of inefficient maintenance and cleaning are more likely to be objectionable. Waring (9), in 1896, said that if all the streets of New York City were given, where the grades would permit, a smooth pavement and a proper relation established between the pavement and the street car tracks, the cost of sweeping the entire city would be reduced by $500 000 per annum. Waring used the sheet-asphalt pavement as an example of a smooth pavement, but the application is equally as great in the case of properly constructed and maintained cement grouted brick pavements, which are as easily cleaned in most cases as the sheet-asphalt. Brick pavements with bituminous joints are not as easily cleaned as bitum-

inous pavements, but they are more easily cleaned than cement-concrete pavements, because of the greater porosity of the latter and as the usual rough surface of the cement-concrete pavement gives greater adhesion to foreign matter coming on it.

Noiselessness. The importance of this factor in a pavement is being more and more appreciated. One serious objection that has been raised to brick pavements in the past, and is still interfering with their selection in many cases, is that they seem to be comparatively noisy, coming perhaps second only to stone block in this respect. As a matter of fact, there have been cases where it was claimed that they were even more noisy than the stone block they replaced. In a letter addressed to the Chairman of the Paving Commission of Baltimore City in 1914, certain abuttors on a street containing one street-car track, and formerly paved with granite block on a gravel foundation, stated that "the brick are noisier than the Belgian blocks they replaced." The new construction consisted of sheet-asphalt from each curb to the nearest rail and vitrified brick with cement filler between the rails, all being laid on a cement-concrete base. Similar instances of an apparent increase in the noisiness by the substitution, within the street railway areas on a number of streets in Baltimore, of brick for stone block or other pavements, compels the consideration of this matter. Unquestionably the brick are more resonant than the more massive stone block, bituminous concrete, or even cement-concrete and macadam. Furthermore, the smoother surface of the cement grouted brick pavement may act as a better reflector to the sound produced upon it than the rougher surface of the other pavements, such as stone block for instance, where the surfaces of individual blocks are probably not as smooth as the brick and the surface of the pavement itself does not approach as closely to a single plane as does the surface of the cement grouted brick pavement. Consequently the sound may be more or less broken up in the case of the stone block surface and not so directly and effectively reflected. The reflection of sound may be compared perhaps to the reflection of light which is normally most efficient from a polished and non-absorbent surface like that of a mirror of silvered glass. The comparative noiselessness or noisiness of cement grouted and bituminous filled brick pavements is a controversial question, and until some standards for measuring noise have been devised, a settlement of the question in any case will probably be largely on a basis of opinion. With a cement filler the reverberating qualities of the brick pavement are at the maximum and any hollow rumblings, such as frequently occur from unequal bedding of the brick and the displacement of the sand cushion are more readily transmitted to adjacent stores and buildings, and apparently magnified there. The brick pavements with bituminous joints do not produce the roaring hollow sound which so often emanates from cement grouted brick pavements and which is frequently objected to seriously. On the other hand, the pavements with bituminous joints do give forth a sharp rattling noise owing to the inevitable wearing out or sinking of the bituminous filler between the brick and the striking of the hard tires of vehicles on the edges of the brick, and this noise is sometimes seriously objected to. The noiselessness of bituminous pavements and of macadam is extreme, especially in the case of the former. The noiselessness of cement-concrete is usually nearer that of macadam than is the case of any brick pavement.

Acceptability or agreeableness to æsthetic or personal demands on the pavement will be determined by local conditions and the character of the

pavement. Under some conditions, the light color of fire clay brick is an argument for its selection. In others, it may be an argument against it, and the same may be said of the reddish colored shale brick and the bluish or grayish slag brick. If the first cost of the pavement is largely paid by the abutting property owners, it may be fair to take into consideration, when the selection of the surfacing is to be made, the preferences of these abuttors for any peculiarities of a particular kind of pavement.

Favorableness to Travel, meaning the ease and comfort enjoyed in driving over a pavement, may or may not argue for the selection of a brick pavement according to the character of the traffic. If the traffic consists largely of horse-drawn pleasure vehicles, the rigidity of a brick pavement will quite likely be offensive, and such a pavement as a bituminous pavement with its greater resiliency may be preferred. Brick pavements seem a little more rigid than some cement-concrete pavements, altho there may not be much difference in this respect. Further statements as to the relative advantages and disadvantages of brick pavements may be found in Sects. 4 and 24.

3. Foundations and Curbs

Brick pavements are laid both with and without artificial foundations. Modern practice generally calls for an artificial foundation of Portland cement-concrete to be provided. There can be no question, in view of the extremely satisfactory experiences in many places where an artificial foundation has been omitted, that a practice of always providing a concrete foundation would be extravagant. A subgrade of gravel or sand properly prepared is frequently all that is necessary to give an ample foundation for a brick pavement, especially where the traffic over the latter is not likely to be of the most severe type within a reasonable period. An excellent instance of the satisfactory wear of a brick pavement on a sandy base and under fairly heavy traffic may be found on West Chase St., Baltimore. This pavement was laid in 1902, and was in excellent condition in 1916. The street is on the crest of a slight ridge running east and west, the subgrade is gravel or sandy gravel and the drainage naturally is all that could be desired. Other instances of the successful omission of concrete foundation may be found in the naturally sandy sections of such towns as Miami, Fla., and elsewhere. It is absolutely necessary, where an artificial foundation is to be omitted, that the natural foundation or subgrade shall be properly prepared by thoroly and evenly compacting the same and by carefully shaping it so that a uniform support and cushion may be accorded the brick pavement. The cost should be but little greater than the cost of the same work necessary before the placing of the concrete or other artificial foundation. The saving in first cost of the pavement will be from 50 to 75 cents per sq yd, and in the annual cost of the pavement, interest on this saving may be upward of 3 cents per sq yd.

The Natural Foundation or subgrade for a brick pavement should be carefully prepared whether or not an artificial foundation is to be placed on it. The importance of proper preparation of the natural foundation, in cases where the cushion and wearing course are to rest directly on the foundation, is often greater than when artificial foundations are to be provided, particularly in view of the greater difficulties sometimes encountered with the work of preparation in the former cases.

In any event, the somewhat usual practice of neglecting the preparation of the natural foundation and of relying on the artificial foundation to

make up for the defects of the natural foundation should be avoided. The natural foundation must be properly drained and thoroly compacted and, as nearly as may be practicable, brought to the proper grades, cross-sections and uniformity of surface, if economy in the design and construction of the subsequent work is to be expected. In these respects, the importance of the proper preparation of the natural foundation for a brick pavement and of an artificial foundation differs along no line except in degree perhaps, from the importance of the proper preparation of the foundation and subgrade for a macadam road-crust. The natural foundation should preferably be thoroly consolidated by a roller similar to that used in macadam work and, when once prepared, should be kept as free from disturbance as possible during the interval occupied by placing the artificial foundation. Any natural foundation which may be expected to suffer displacement, or to permit a displacement of the sand cushion placed on it, should have its defects in these respects remedied, or it should be supplemented by an artificial foundation over it.

Laylin (42) states, that "Many of the brick pavements in northern Ohio on streets and roads having a sandy or gravelly soil, are laid on natural bed foundation, and where traffic is light or medium, such streets are giving first-class service. Many such streets have been in use twenty years and more, and they give every evidence of being good construction." See also (21) and (39).

Rolling. The natural foundation should always be thoroly compacted, where practicable by rolling as referred to in Art. 9, even when an artificial foundation is to be placed thereon. In cases, such as of extremely sandy road-beds, where steam rolling may be impossible, compaction by a horse-drawn roller may be the necessary resort. A steam roller should be used whenever possible and the embankments and subgrades thoroly rolled, any depressions being filled with material similar to the rest of the foundation and rerolled until the surface is uniformly firm, even and at the proper elevations.

Artificial Foundations for brick pavements are, as has been noted, generally of Portland cement-concrete. The usual practice has been to make concrete foundations 6 in in thickness, but it is likely that some extravagance has been incurred by the adoption of this convenient figure. This is especially true where the filling of the joints in the pavement has subsequently been of high character and with Portland cement grout. Brick pavements are not expected to be economical under the most severe type of traffic, and therefore, where other conditions justify the selection of such a pavement, it is also quite frequently true that a 4 or 5 in concrete foundation will answer every purpose, and permit a saving to be made, especially under the modern practice of more carefully and thoroly preparing the subgrade. Other kinds of artificial foundations for brick pavements have been used, such as broken stone, gravel or slag roads, heavy layers of compacted gravel or sand, brick laid on a layer of sand, and plank. The use of the brick and plank foundations has been found unsatisfactory and has practically ceased. See (33).

Uniformity and Evenness of Surface in the case of rigid artificial foundations are especially important, because of the relatively greater emphasis in the results brought about by the greater rigidity usually had from artificial foundations. Lack of uniformity therefore is more apparent on the surface of the pavement in course of time, than would be the case where there was lack of uniformity at the start as in the instance of natural

foundations. Evenness of surface for artificial foundations is necessary in order to secure uniformity in the thickness of the cushion. The importance of this uniformity is set forth in Art. 11. The tendency is increasing to require greater attention to the securing of a most even surface of such artificial foundations as cement-concrete.

Macadam Foundations have been used to support wearing courses of vitrified brick with more or less success. If the macadam has been thoroly compacted and settled into an enduring and reasonably rigid form, and the surface of the old macadam was not so uneven as to permit too great a variation in the thickness of the sand cushion, the results have been fairly satisfactory. On the other hand, where the macadam was insufficiently rigid or compact and so uneven on its surface as to require a sand cushion greatly varying in thickness at different points, the final results were unsatisfactory.

Broken Stone, Slag or Gravel Foundations have been more or less successful on the same principle. The defect of such foundations, usually rather loosely compacted, is that they permit the escape of a certain amount of sand cushion down into their interstices, which results in uneven settlement and often breaking up of the brick wearing course.

Rolling. The artificial foundation may or may not properly be rolled, according to its character. At any rate, it should be thoroly and uniformly compacted by such means as are most appropriate. If of broken stone, gravel or similar material, it should be thoroly rolled to the utmost possible compaction by a 10-ton three-wheeled steam roller. The use of a double drum roller will be unsatisfactory because of the uneven compaction resulting from such use of this roller. The bridging of compressible areas in the material by the long drums results in places being left in the layer which afterward produce unevenness in its surface and eventually in the surface of the pavement itself. With a three-wheeled roller, these weak spots should be discovered and may be remedied before being covered up. Cement-concrete is not usually rolled after being mixed and placed tho it may be. The effort is usually made, however, to compact the concrete to some extent at least by ramming it in place. While this does produce some degree of compaction, the uniformity of compaction is questionable in many cases and rolling, if practicable, would be better. Broken stone, rolled and then grouted with cement mortar so as to produce in situ a cement-concrete would form a strong foundation for a brick pavement but the difficulties in the way of securing a sufficiently even surface uniformly at the proper elevations so as to provide for a uniform thickness in the sand cushion may be insuperable.

Curbs have usually been considered necessary along brick pavements for the purpose of preventing the outside brick from breaking away under traffic crossing from the pavement to the shoulder and the consequent ultimate destruction of the pavement. Wooden curbs have been used with more or less success in many cases of country roads. Usually it has been considered better practice to build cement-concrete curbs from 4 to 6 in in width and extending as low as the base of the artificial foundation. The objection to such curbs is their first cost and the extreme difference in rigidity between them and the material forming the shoulder outside of them. This results in a tendency for a rut to form along the curb and just outside of it in the shoulder material which rut serves to collect water which will materially affect the foundation. Further, unless the shoulders are well maintained outside the curb, the wheels of vehicles attempting

to reach the pavement from the shoulder, find difficulty in climbing up over the edge of the curb, and if iron-tired, tend to destroy the curb itself. A suggestion for obviating the difficulties produced by curbs, and tried successfully to some extent, consists of constructing on a cement-concrete foundation a lug projecting upward from the upper surface of the concrete about 2 in just outside the edge of the sand cushion of the pavement. This necessitates making the concrete foundation from 3 to 6 in wider than the pavement in order to give a substantial width to each lug, and results in a sunken curb holding the sand cushion and the lower edge of the vitrified brick in place. The cement filler, together with the support of selected shoulder material against the outside of the brick, is claimed to furnish sufficient strength for keeping the brick in place, and at the same time to avoid in part at least the cost and other objectionable features of a rigid curb along the edges of the pavement.

MATERIALS

4. Shale and Fire-Clay Brick

The Three Principal Paving Bricks now in use are the vitrified shale brick, vitrified fire-clay brick, and the slag or scoria blocks. Probably the use of the shale brick is at present greater than that of the other two combined. The shale brick are made of a proper mixture of suitable clay and shale, dependent upon the characteristics of each of the materials available in a given locality. The mixture is carefully and intimately made after the materials have been ground or otherwise prepared so as to permit their proper incorporation, and every effort is, or should be, made to obtain a homogeneous mixture. The mixing is done with the aid of water, and when of the proper consistency, the material is passed thru rolls, cutters and presses to form the individual blocks. These blocks are dried and then roasted in kilns until an approach to vitrification of the blocks is had, when the fires are reduced and the contents of the kilns gradually cooled or annealed. Modifications in the above processes produce different types of bricks. See (36).

Repressed Brick are made by repressing in molds, before roasting, the rough brick as they originally come from the cutters. Most repressed brick have projections in the form of lugs or raised letters on one or both sides, intended to bring about a slight and uniform separation of the rows of brick when laid in a pavement, with the idea that better joints may be had thereby. Some repressed brick have letters on their sides depressed into one face in order to permit the joint material to get a better hold on the brick.

Wire Cut Brick are formed directly from a ribbon of the soft material proceeding from the mixing machine, and are not repressed. They are of both kinds, smooth and with lugs. They are generally somewhat rougher in appearance than the repressed brick, but it is represented that they are more uniform, and both stronger and tougher than repressed block, because the repressing is claimed to disturb the molecular structure injuriously.

Vertical Fiber Brick are so cut from the ribbon of material that the surface of the brick exposed to traffic, as ordinarily laid in a pavement, is perpendicular to the axis of the ribbon as it comes from the rolls. Any fibers in the ribbon would therefore be perpendicular to the surface of the brick when so laid, as is the case with the wood fibers in a wood block pavement. See (27).

Tucker (54a) presents the differences between repressed brick and vertical fiber brick as follows: "The first difference relates to putting the fiber of the brick in a vertical position in the pavement. Experiments with an auger machine prove conclusively that, as the clay column is forced thru the die of the auger machine, there is a well-pronounced arrangement of the plastic material in concentric layers. This arrangement of material is closely represented by the fiber in wood. The clay column is cut into blocks by wire in the usual fashion, but instead of being passed to the repressing machine, the green blocks are immediately passed to the dryers and thence into the kilns. The auger machine expends perhaps 75 h p of energy in compressing the material and building up the fibrous structure just mentioned. These blocks are ordinarily passed to the repressing machine where the movable sides of the die bring a heavy pressure to bear on the six surfaces of the block, effectually upsetting or breaking down the fibrous structure previously obtained besides expending a considerable amount of energy to undo what the auger machine has just done.

"Other differences are that the repressed brick has smoother surfaces, is habitually given rounded edges, and usually carries the maker's name. The new style of block is purposely left as square-edged as the process of manufacture will permit, is cut by a coarse wire with a view to producing a roughened surface, and therefore has only the four smooth surfaces given by the sides of the die in the auger machine. It has been common practice to so proportion the repressed brick that each brick went into the pavement lying on its side so far as the fiber was concerned, tho on edge as to size, the effect being as if wood paving blocks were laid with their grain parallel to the direction of traffic, instead of having it vertical. On the hypothesis of a fibrous structure it appears that the resistance to wear should be much greater if the fibers are placed vertically in the pavement instead of lying flat since the tendency to spall or break is thereby greatly lessened. The vertical-fiber method of laying brick is now carried out. The dimensions of the brick are 8¼ by 3½ by 3 in, and they are laid flatwise; that is, with the 3-in dimension vertical.

"From the manufacturer's standpoint, there is a considerable saving of material due to lessening the pavement thickness. Also, as the bricks have their larger dimensions flatwise, a less number of bricks is required to the square yard and substantial savings may be thereby made, while the consequent lessening of cost tends to popularize brick paving. Also the cost of power required to operate the repressing machine is saved, as well as the extra hauling required to put the brick thru it." See (54b).

Fire-Clay Brick are made from fusible, plastic clays, selected for the purpose, with or without an admixture of sand, in much the same manner and form as are shale brick, tho usually of smaller size than the latter. They are supposed to be somewhat softer and less brittle than shale brick, but the difficulties of securing proper materials and of their manufacture has interfered with their serious competition, except locally, with the shale brick, and their use is much less extensive.

5. Scoria or Slag Blocks

Scoria or Slag Blocks are usually cast in molds from the molten slag forming the waste or by-product from blast furnaces for producing iron. These slags vary a great deal in composition according to the character of the iron ores being used, and the character of the flux employed for their purification. The acid slags, being more vitreous, are the ones suitable for brick making. Not all of the acid slags, however, can be used to advantage for slag brick, and the details of the methods of manufacture are important. Proper annealing of the brick is somewhat difficult but absolutely necessary for success. Good slag brick appear to stand up better, under fairly heavy traffic, than do shale or fire clay brick. They are often, however, unfairly reputed to be somewhat more slippery than the others.

An Analysis of a Slag Block taken at random from a lot being used in 1914 in Balti-

more, Md., and supposed to have come from England, was as follows: Size of block, 3½ by 4 by 8 in, edges bevelled on one face; weight, 10.56 lb; specific gravity, 2.684.

Chemical Analysis

Silica	34.43%
Alumina	29.68%
Oxide of iron	4.00%
Lime	11.73%
Magnesia	10.02%
Alkalies	1.15%
Sulphuric acid	8.99%
	100.00%

6. Physical Properties of Brick

The quality of a paving brick depends upon its density, hardness, imperviousness, resistance to cross breaking and crushing strains, toughness, and uniformity or homogeneity of character.

Form and Size. Paving brick are, approximately at least, rectangular in section each way, tho the edges of the faces intended to be exposed in the pavement are frequently rounded slightly at the corners, especially in the case of repressed and slag brick. Originally, paving brick were made in various sizes, some makes being practically identical in size with the ordinary building brick, that is, 2 by 4 by 8 in, while variations from this size up to what might be called tiles, 12 by 12 by 4 or 6 in thick were not uncommon. The standard size for shale brick now is 3½ by 4 by 8½ in; for fire clay brick, 2½ by 4 by 8½ in; and for slag brick, 3½ by 4 by 8 in. In repressed brick, if the edges are rounded the radius should not exceed 3/16 in and any lugs or projections on the side of the brick should be not greater than ¼ in beyond the plane of the side. Variations in width and depth should not exceed ⅛ in, nor in length be more than ½ in.

Reduction in Depth of Brick (49c). "Since the advent of the monolithic and semi-monolithic construction there is a tendency among paving engineers to reduce the depth of the brick from 4 to 3 in. If a 3-in brick laid directly in the green concrete, or on a cement-sand superfoundation will give as durable a wearing surface as a 4-in brick, there would be considerable saving in the cost of brick paving, especially in districts at a distance from the brick plants. The paving engineer in preparing his estimates should investigate the saving in 1 in of brick as compared with 1 in of the prepared foundation, and prepare his plans and cross-section of pavement accordingly. In the manufacture of 3-in paving brick there is a little saving in cost at the plant; the main saving, however, being in the transportation charges. A thousand 3-in paving brick weigh about 7500 lb which is a saving in weight of approximately 2500 lb over that of a 4-in brick. This would mean on a shipment of brick to New York City from the eastern Ohio district a saving of about 16 cents per sq yd of brick surface. To the contractor there is a considerable saving in the use of a 3-in paving brick. He can haul one-third more brick per load; the manipulation of handling and laying would be faster; they would require one-fourth less grout or bonding material and also require less excavation. Many engineers are taking advantage of these savings and there has been an increasing demand for 3-in brick during the year 1916."

Number per Square Yard of Pavement. With fire-clay brick of the size above given, allowing for joints, 58 will be required to the square yard of pavement if the brick are laid on edge, and 38 brick per square yard if they are laid flatwise. With shale brick laid edgewise, 43 will be required to the square yard, and 38, if laid flatwise.

The Color of shale brick is usually a dark red, more or less mottled or speckled with small blue or yellowish white spots; that of fire-clay brick is usually yellow or yellowish white; and that of slag brick, light blue or bluish gray. All these paving brick have a skin or superficial coat more

vitreous in character than the interior of the brick, and generally darker in color. As this skin is broken or worn off, the wear of the exposed interior mass is often perceptibly different under traffic. Too great a variation in color between the outside and the inside of any brick therefore indicates a difference in character and possibly to an objectionable extent.

The color of paving brick is no criterion for comparing brick made from different clays, tho for a given clay it may be a reliable guide, if burned under the same conditions, as to the heat it has received. Uniformity of color thruout a broken brick is a valuable guide for checking up the work of the burner, as too dark a center shows varied firing, while a too light-colored center shows insufficient time in holding the heat. Homogeneity, density and degree of vitrification may be judged by the appearance of the fracture on breaking a brick, and there should be apparent no large spots of unfused matter in glassy or spongy spots, no lack of uniformity, no shakes or marked laminations.

Density is a desirable factor in paving brick, as, other things being equal, with the denser brick, the greater quantity of wearing material is had in a given space. The density is usually expressed in terms of specific gravity, the shale brick ranging from 2.05 to 2.55; the fire-clay brick from 1.95 to 2.30; and the slag brick from 2.5 to 3.0.

Hardness is the property resisting the attrition of the tires, especially when the brakes are applied, and of horses' shoes. It is probably next to toughness as an important requisite of good paving brick.

Imperviousness is an indication of the degree of vitrification, as a sound and perfectly vitrified brick is non-porous. Fire-clay brick rarely absorb less than 2% on 24 hr soaking in water, and often over 5% without much injury to their use in pavements. Shale brick range from 1 to 2½%, while slag brick show even less absorption. Too little absorption may be indicative of brittleness. The National Paving Brick Manufacturess Association takes the position that the absorption test is unnecessary, in that the rattler test gives all the necessary information.

Tillson (8) says: "The porosity of a paving brick is one that can be easily tested and has received considerable attention by engineers. It has been generally considered that 2% is the maximum amount of absorption that a good paving brick should be allowed. Very few good shale bricks will exceed this, but bricks manufactured from fire-clays, which from their nature are incapable of vitrification, will in almost every case absorb more than this amount. It has generally been considered that the danger of absorption in a paving brick was similar to that in building bricks, that is, its liability to disintegrate under the action of frost, but it must be remembered that paving brick and building brick are two different substances. In order to reach the point of vitrification, brick have been subjected to such severe heat that they have acquired a strength which is fully able to withstand all actions of the frost, and tests made have borne out this view of the question. Tests for porosity, however, are valuable, as they indicate, in a way not otherwise possible, the amount of vitrification that has taken place, especially on the exterior. If the brick are thoroly vitrified they cannot be porous and absorb any appreciable amount of water."

The Resistance to Crushing and Cross-Breaking Strains should be regarded in the light of the strains likely to come on any individual brick in the pavement. Usually these tests are omitted. Paving brick vary greatly in crushing resistance, ranging between 4 000 and 30 000 lb per sq in. Cross-breaking resistance ranges from 1 000 to 3 500 lb per sq in of cross-section when tested between supports 6 in apart and loaded midway. With the sand cushion under a brick pavement and the other precautions taken in constructing a pavement, a test for the cross-breaking strength is rarely needed.

Toughness is a most vital property in a brick for pavement purposes, for toughness is the ability to resist the most severe of the destructive agencies of the pavement, that is, the shocks of traffic. The rattler test (see Art. 9) for toughness has been fairly well standardized. As a matter of fact, this test for toughness, when properly carried out, frequently obviates the necessity for any of the other tests above mentioned, except perhaps those made thru visual inspection as already indicated. A test for toughness or resistance to spalling, or chipping off at the edges under shock, has been proposed, but it has not as yet been standardized, nor does it seem to have been generally accepted in principle. Green (34) has conducted a series of tests, with the Page impact machine, to investigate the relationship between toughness and the loss on abrasion in the standard rattler tests. Typical results of tests are given in Table I.

Table I

Method of Manufacture	Average Toughness of Surface Cores	Percentage Rattler Loss	Method of Manufacture	Average Toughness of Surface Cores	Percentage Rattler Loss
Wire Cut . . .	10.5	15.5	Repressed . . .	9.0	15.0
Wire Cut . . .	12.0	16.0	Repressed . . .	7.5	15.1
Wire Cut . . .	10.0	16.3	Repressed . . .	6.0	16.8
Wire Cut . . .	10.0	17.2	Repressed . . .	7.5	16.9
Wire Cut . . .	9.0	19.4	Repressed . . .	7.5	17.6
Wire Cut . . .	5.0	19.9	Repressed . . .	9.0	19.1
Wire Cut . . .	10.0	20.0	Repressed . . .	4.0	19.7
Wire Cut . . .	9.0	20.0	Repressed . . .	7.0	20.2
Wire Cut . . .	4.5	20.2	Repressed . . .	6.0	20.6
Wire Cut . . .	5.5	20.8	Repressed . . .	7.0	20.7
Wire Cut . . .	9.3	21.0			

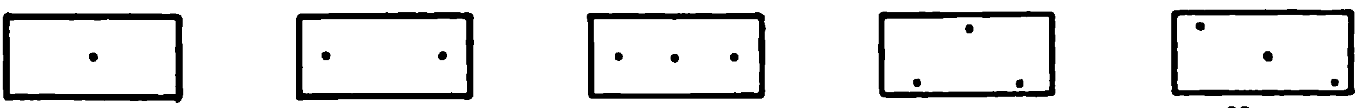
The Uniformity or Homogeneity of paving brick in all respects is most important, and this applies to a lot of brick as well as to the individual specimen. It is obvious that variation in the individual bricks composing a pavement will result in lack of uniformity in the resistance of the pavement to wear under traffic, just as lack of uniformity in the composition of the individual specimen will result in lowering its resistance to wear. Brick pavements can frequently be so unevenly worn as to be unsatisfactory in their condition, or even to warrant their relaying, because of the numerous holes in the surface caused from the more rapid wear of one or two brick which have been surrounded, as laid, by more resistant brick. Had the brick worn more uniformly thruout the pavement, while the total wear of the pavement would have perhaps been greater, its existing condition of surface would have been far less unsatisfactory. A great defect of the tests now generally made on paving brick is that they do not usually provide for special consideration on this point. See Arts. 8 and 9. See also (13). For about 1000 records of brick tests, see (44a) and (44b).

Tillson (8) says: "All products of the same kiln should be uniformly burned. While this is sometimes difficult to be obtained, if proper care is exercised in the burning, and the brick are selected at the kiln before shipment, satisfactory results can be secured in almost every instance. A better pavement will result from a lot of brick that are uniformly burned, even if not fully up to the required standard, than from a lot which is perhaps one-half perfect and the other half somewhat inferior, for when subjected to traffic the harder brick will maintain their size, while the softer brick will wear and the entire surface soon become rough and uneven and very disagreeable for travel."

Tests on Individual Brick. Provision should be made for securing information as to the uniformity, or lack of it, in the losses of the individual brick, or, as they are samples, of the lot of brick they represent. The

necessity for uniformity among the individual brick composing a pavement has already been generally recognized. Further discussion on the subject may be found in (24) and (47a). Specifications such as those of the Am. Soc. Test. Mat. (see Art. 9) or of the Am. Soc. Mun. Imp. should have added to them a clause like that in the specifications of the Md. Road Comm., thus: "The losses in the rattler test shall not average more than ......, nor shall the difference between the maximum and minimum losses in the rattler test exceed ten points." See (44b), (51a), (51b) and (52b).

Illinois Practice (51a). "The bricks are marked with a compressed air drill making a hole only 1/10 in in diameter, and ¼ in deep (see Fig. 1). Approximately 200 rattler tests have been performed during the past years, using the above scheme of identifica-



No. 1 No. 2 No. 3 No. 4 No. 5

Same as above with one hole on opposite side

No. 6 No. 7 No. 8 No. 9 No. 10

Fig. 1. Roman Method of Marking Paving Brick for Rattler Test

tion, and it has been noted that very few of the bricks which broke, or chipped, in the rattler were broken thru a drill hole. A number of comparative rattler tests were performed with marked and unmarked bricks, and it has been found that the drilling of the small holes used in marking did not cause any appreciable increase in the rattler loss. It has been noted in practice that a shipment of bricks showing a fairly high average rattler loss and uniform wearing qualities, will often make a better pavement than bricks showing a low average loss, but also rather wide variations in wearing qualities."

Newark, N. J., Method and Tests (40). "The system of marking bricks, which is in use in a number of cities, is as follows: (1) drill hole on the flat part; (2) one drill hole on the top part; (3) one drill hole on each flat portion; (4) one drill hole on top and bottom; (5) one drill hole on the end; (6) one drill hole on each end; (7) two drill holes on flat part; (8) two drill holes on the top part; (9) one on top and one on end; (10) blank. The drill holes can be put in the bricks by a man accustomed to do that kind of work in from 20 to 25 min. There are but 15 holes to be drilled."

Table II.—Percentage Lost by Each Brick in Rattler (40)

Samples	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10	Aver.
1	24.0	24.0	24.5	24.5	25.0	19.0	19.5	19.5	20.0	20.0	22.00
2	20.5	20.5	20.5	21.0	21.5	22.0	21.5	25.0	25.5	26.0	22.30
3	21.0	21.5	21.5	22.0	22.0	21.7	21.8	20.8	22.0	28.5	22.28
4	21.0	21.3	21.4	21.2	22.0	22.0	21.9	21.7	23.5	29.5	22.55
5	20.0	20.5	21.0	21.5	22.0	22.0	22.0	22.0	22.0	32.0	22.50

Table III.—Typical Tests on Individual Brick Made by Maryland Geological Survey (44b)

Number of Test	Percentage Lost by Each Brick in Rattler, 1800 Revolutions										
	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10	Aver.
218	10	13	13	15	15	15	16	23	36	..	18
225	20	20	24	25	25	26	30	31	34	..	26
231	18	21	23	24	24	24	25	29	37	..	25
242	20	22	22	23	24	26	26	27	28	42	26
254	18	20	24	25	26	26	31	33	35	..	26
266	15	15	17	18	20	23	25	32	59	..	25
268	17	17	18	20	20	22	22	24	32	..	21
272	13	17	17	17	20	20	23	26	44	..	22
273	11	11	12	16	17	18	23	27	36	..	19
280	18	19	21	22	22	23	28	30	30	..	23

7. Sampling Brick

The following method was adopted at the First Conference of State Highway Testing Engineers and Chemists held under the auspices of the U. S. O. P. R. in Feb., 1917.

"**Inspection.** Vitrified bricks may be inspected and tested at the point of manufacture, or they may be sampled at the point of delivery, and representative samples submitted to the laboratory for testing prior to acceptance of the shipment.

"**Plant Inspection.** Whenever practicable the inspection and testing of vitrified bricks shall be carried on at the manufacturer's plant. The choice between plant inspection and sampling at point of use should be based om the average number of brick to be shipped from the plant per day, and the total number required for the particular piece of work. Whenever conditions permit, samples should be taken directly from the kiln during the process of emptying. One or more sets of tests, depending upon the size of the kiln, each set consisting of three separate tests, should be made on each kiln. Each test in a set cf three should represent approximately a single degree of burning, based on the position of the bricks in the kiln, and all ten of the bricks in a single test should be of the same approximate degree of burning. The average abrasion loss in three such tests will determine whether the contents of a kiln or part of a kiln meet the average maximum abrasion loss specified; and the maximum variation between the percent abrasion losses of the three sets will be used to determine what portion of the bricks represented will be culled or rejected.

"**Sampling from PILES at the plant.** In general, samples selected from piles at the plant shall be as nearly as possible representative of the entire run of the bricks. Samples from piles shall be taken from as many different points corresponding to the length, breadth and depth of the pile as possible. In no case shall they be confined to the upper or outer few layers. Where controversy arises regarding the admissibility of certain types or portions of the lot, entire test samples may be selected from such types or portions having a characteristic appearance in common.

"**Sampling at Point of Delivery.** A representative sample should be taken from each carload received. Considerations covered under Sampling from Piles at the Plant apply equally to sampling from cars.

"**Shipping.** Samples shipped by freight or express to the laboratory shall be put up in packages containing 12 bricks each, packed in two rows separated by a partition for protection.

"**Condition of Bricks before Testing.** If bricks are damp, they shall be dried at a temperature of 89° C (100° F) before testing. No bricks shall be included in the test lot which would be rejected on the basis of cracks, chips, or other defects covered by the specification clauses for visual inspection."

The method adopted by the Am. Soc. Test. Mat. is described in Art. 9.

8. Methods of Testing Brick

Tests for Quality of Paving Brick usually made are now generally confined to one, the rattler test. Sometimes, however, a test is made for absorption and for the cross-breaking strength. Specifications also generally include clauses concerning the visual inspection of the brick in order to provide for especial uniformity in size and shape, and for homogeneity and freedom from flaws, nodules, voids, etc in internal composition.

The Absorption Test, when made, is usually carried out as follows: Five brick, which have been thru the rattler test, are thoroly dried and their weights recorded. They are then immersed in water for 48 hr, removed and dried superficially with blotting paper, and again weighed. The gain in weight is calculated and reported as the absorption, the percentage being based on the weight of the brick.

The Cross-Breaking or Transverse Test is as follows: The brick is supported upon two knife edges and a load is applied on the upper side midway between the supports by means of a third knife edge. The load is gradually

increased until rupture occurs. The result of the test is expressed in the ratio of the fraction $\frac{3\,P\,L}{2\,B\,D^2}$ called the modulus of rupture. In the fraction, P represents the breaking loads in pounds, L the distance between the supports, B the breadth of the specimen, and D the depth of the specimen, measured in inches. In making the test, a number of individual samples should be used so that a fair average of the lot may be obtained.

Rattler Test. For a description of the standard method of making the rattler test, see the Standard Specifications for Paving Brick of the Am. Soc. Test. Mat. given in Art. 9.

9. Specifications for Brick

The First Conference, 1917, State Highway Engineers and Chemists adopted the following specifications for paving brick.

All brick shall be of a size commercially known as vitrified block. They shall be thoroly annealed, tough and durable, regular in size and shape and evenly burned. When broken the bricks shall show a dense, stone-like body, free from lime, air pockets, cracks or marked laminations. Kiln marks shall not exceed .... of an inch, and the wearing surface shall show but slight kiln marks.

"Rattler Test. Representative samples of the brick shall meet the following requirements when subjected to the rattler test. Average loss by abrasion on one or more tests, not more than ....%. Maximum difference in percent loss by abrasion when more than one representative sample is tested, not more than ....%. A maximum of three tests will be used as a basis for rejection.

"Dimensions. The brick shall meet the following requirements: Length, ... inches to .... inches; width, ... inches to .... inches; depth, ... inches to .... inches.

"Variations among brick from a single plant shall not exceed the following limits: Variation in length, ... of an inch; variation in width, ... of an inch; variation in depth, ... of an inch.

"If the edges of the brick are rounded, the radius shall not exceed .... of an inch. Only brick with lugs on one side, raised not less than .... of an inch, nor more than .... of an inch, shall be used.

"Visual Inspection. The bricks shall be subjected to inspection subsequent to delivery at the place of use, prior to and during laying, in order to cull out and reject upon variations from the general and dimensions clauses and upon the following grounds: All bricks which are broken thru, or chipped in such manner that neither wearing surface remains substantially intact, or in such manner that the lower or bearing surface is reduced in area by more than one fifth. All bricks which are cracked to a depth greater than .... inch on any surface, or which are cracked on the wearing surface. All bricks which are so off-size or so misshaped, bent, twisted, or kiln-marked that they will not form a proper surface or align properly with other bricks. All bricks which are obviously too soft and too poorly vitrified to endure street wear."

The Am. Soc. Test. Mat. standard specifications for paving brick adopted in 1916, are as follows:

"The quality and acceptability of paving brick, in the absence of other special tests mutually agreed upon in advance by the seller on the one side and the buyer on the other side, shall be determined by the following procedure:

1. The Rattler Test, for the purpose of determining whether the material as a whole possesses to a sufficient degree strength, toughness and hardness.

2. Visual Inspection, for the purpose of determining whether the physical properties of the material as to dimensions, accuracy and uniformity of shape and color, are in general satisfactory, and for the purpose of culling out from the shipment individually imperfect or unsatisfactory brick.

"The acceptance of paving brick as satisfactorily meeting one of these tests, shall not be construed as in any way waiving the other.

"The Selection of Samples for Test. 1. PLACE OF SAMPLING. In general, where a

shipment of bricks involving a quantity of less than 100 000 is under consideration, the sampling may be done either at the brick factory prior to shipment, or on cars at their destination or on the street, when delivered ready for use. When the quantity under consideration exceeds 100 000 the sampling shall be done at the factory prior to shipment. Bricks accepted as the result of test prior to shipment, shall not be liable to subsequent rejection as a whole, but are subject to such culling as is provided for under Visual Inspection.

"2. METHOD OF SELECTING SAMPLES. In general, the buyer shall select his own samples from the material which the seller proposes to furnish. The seller shall have the right to be present during the selection of a sample. The sampler shall endeavor, to the best of his judgment, to select brick representing the average of the lot. No samples shall include bricks which would be rejected by visual inspection, except, that where controversy arises, whole tests may be selected to determine the admissibility of certain types or portions of the lot having a characteristic appearance in common. In cases, where prolonged controversy occurs between buyer and seller and samples selected by each party fail to show reasonable concurrence, then both parties shall unite in the selection of a disinterested person to select the samples, and both parties shall be bound by the results of samples thus selected.

"3. NUMBER OF SAMPLES PER LOT. In general, one sample of ten bricks shall be tested for every 10 000 bricks contained in the lot under consideration; but where the total quantity exceeds 100 000, the number of samples tested may be fewer than one per 10 000, provided, that they shall be distributed as uniformly as practicable over the entire lot.

"4. SHIPMENT OF SAMPLES. Samples which must be transported long distances by freight or express, shall be carefully put up in packages holding not more than twelve bricks each. When more than six bricks are shipped in one package, it shall be so arranged as to carry two parallel rows of bricks side by side, and these rows shall be separated by a partition. In event of some of the bricks being cracked or broken in transit, the sample shall be disqualified, if there are not remaining ten sound undamaged bricks.

"5. STORAGE AND CARE OF SAMPLES. Samples shall be carefully handled to avoid breakage or injury. They shall be kept in the dry so far as practicable. If wet, when received, or known to have been immersed or subjected to recent prolonged wetting, they shall be dried for at least 6 hr in a temperature of 38° C (100° F) before testing.

" The Construction of the Rattler. 6. GENERAL DESIGN. The machine shall be of good mechanical construction, self-contained, and shall conform to the following details of material and dimensions, and shall consist of barrel, frame, and driving mechanism as herein described.

"7. THE BARREL. The barrel of the machine shall be made up of the heads, head-liners, staves and stave-liners. The heads may be cast in one piece with the trunnions, which shall be 2½ in in diameter, and shall have a bearing 6 in in length, or they may be cast with heavy hubs, which shall be bored out for 2 7/16 in shafts, and shall be key-seated for two keys each ½ by ⅜ in and spaced 90° apart. The shaft shall be a snug fit and when keyed shall be entirely free from lost motion. The distance from the end of the shaft or trunnion to the inside face of the head shall be 15⅜ in in the head for the driving end of the rattler, and 11⅜ in for the other head, and the distance from the face of the hubs to the inside face of the heads shall be 5½ in. The heads shall be not less than ¾ in thick, nor more than ⅞ in thick. In outline, each head shall be a regular 14-sided polygon inscribed in a circle 28⅜ in in diameter. Each head shall be provided with flanges not less than ¾ in thick, and extending outward 2½ in from the inside face of the head to afford a means of fastening the staves. The surface of the flanges of the head shall be smooth and give a true and uniform bearing for the staves. To secure the desired true and uniform bearing the surfaces of the flanges of the head shall be either ground or machined. The flanges shall be slotted on the outer edge, so as to provide for two ¾ in bolts at each end of each stave, said slots to be 13/16 in wide and 2¾ in, center to center. Each slot shall be provided with a recess for the bolt head, which shall act to prevent the turning of the same. Between each two slots there shall be a brace ⅜ in thick, extending down the outward side of the head not less than 2 in. There shall be for each head a cast-iron headliner 1 in in thickness and conforming to the outline of the head, but inscribed in a circle 28⅛ in in diameter. This headliner shall be fastened to the head by seven ⅝-in cap-screws,

thru the head from the outside. Whenever these headliners become worn down ½ in below their initial surface level at any point of their surface, they shall be replaced with new ones. The metal of these headliners shall be hard machinery iron and should contain not less than 1% of combined carbon.

"The staves shall be made of 6-in medium-steel structural channels, 27¼ in long and weighing 15.5 lb per lin ft. The staves shall have two holes 13/16 in in diameter, drilled in each end, the center line of the holes being 1 in from the end and 1⅜ in either way from the longitudinal center line. The spaces between the staves shall be as uniform as practicable, but shall not exceed 5/16 in. The interior or flat side of each stave shall be protected by a liner ⅜ in thick by 5½ in wide by 19¾ in long. The liner shall consist of medium-steel plate, and shall be riveted to the channel by three ½-in rivets, one of which shall be on the center line both ways and the other two on the longitudinal center line and spaced 7 in from the center each way. The rivet holes shall be countersunk on the face of the liner and the rivets shall be driven hot and chipped off flush with the surface of the liners. These liners shall be inspected from time to time, and if found loose shall be at once re-riveted. Any test at the expiration of which a stave-liner is found detached from the stave or seriously out of position, shall be rejected. When a new rattler, in which a complete set of new staves is furnished, is first put into operation, it shall be charged with 400 lb of shot of the same sizes, and in the same proportions as provided in Par. 9, and shall then be run for 18 000 revolutions at the usual prescribed rate of speed. The shot shall then be removed and a standard shot charge inserted, after which the rattler may be charged with brick for a test. No stave shall be used for more than 70 consecutive tests without renewing its lining. Two of the 14 staves shall be removed and relined at a time in such a way that of each pair, one falls upon one side of the barrel and the other upon the opposite side, and also so that the staves changed shall be consecutive but not contiguous; for example, 1 and 8, 3 and 10, 5 and 12, 7 and 14, 2 and 9, 4 and 11, 6 and 13, etc, to the end that the interior of the barrel at all times shall present the same relative condition of repair. The changes in the staves should be made at the time when the shot charges are being corrected, and the record must show the number of charges run since the last pair of new lined staves was placed in position. The staves, when bolted to the heads, shall form a barrel 20 in long, inside measurement, between headliners. The liners of the staves shall be so placed as to drop between the headliners. The staves shall be bolted tightly to the heads by four ¾-in bolts, and each bolt shall be provided with a lock nut, and shall be inspected at not less frequent intervals than every fifth test and all nuts kept tight. A record shall be made after each inspection showing in what condition the bolts were found.

"8. THE FRAME AND DRIVING MECHANISM. The barrel shall be mounted on a cast-iron frame of sufficient strength and rigidity to support it without undue vibration. It shall rest on a rigid foundation with or without the interposition of wooden plates, and shall be fastened thereto by bolts at not less than four points. It shall be driven by gearing whose ratio of driver to driven is not less than one to four. The counter shaft, upon which the driving pinion is mounted, shall not be less than 1 15/16 in in diameter, with bearing not less than 6 in in length. If a belt drive is used the pulley shall not be less than 18 in in diameter and 6½ in in face. A belt at least 6 in in width properly adjusted, to avoid unnecessary slipping, should be used.

"9. THE ABRASIVE CHARGE. The abrasive charge shall consist of cast-iron spheres of two sizes. When new, the larger spheres shall be 3.75 in in diameter and shall weigh approximately 7.5 lb (3.40 kg) each. Ten spheres of this size shall be used. These shall be weighed separately after each ten tests, and if the weight of any large sphere falls to 7 lb (3.175 kg), it shall be discarded and a new one substituted; provided, however, that all of the large spheres shall not be discarded and substituted by new ones at any single time, and that so far as possible the large spheres shall compose a graduated series in various stages of wear. When new, the smaller spheres shall be 1.875 in in diameter and shall weigh approximately 0.95 lb (0.43 kg) each. In general, the number of small spheres in a charge shall not fall below 245 nor exceed 260. The collective weight of the large and small spheres shall be as nearly 300 lb as possible. No small sphere shall be retained in use after it has been worn down so, that it will pass a circular hole 1.75 in in diameter, drilled in an iron plate ¼ in in thickness, or weigh less than 0.75 lb (0.34 kg). Further, the small spheres shall be tested, by passing them over the above plate or by weighing, after every ten tests, and any which

pass thru or fall below the specified weight, shall be replaced by new spheres; provided, further, that all of the small spheres shall not be rejected and replaced by new ones at any one time, and that so far as possible the small spheres shall compose a graduated series in various stages of wear. At any time, that any sphere is found to be broken or defective, it shall at once be replaced. The iron composing these spheres shall have a chemical composition within the following limits: Combined carbon, not under 2.50%; graphitic carbon, not over 0.25%; silicon, not over 1.00%; manganese, not over 0.50%; phosphorus, not over 0.25%; sulphur not over 0.80%. For each new batch of spheres used, the chemical analysis shall be furnished by the maker or be obtained by the user, before introducing into the charge, and unless the analysis meets the above specifications, the batch of spheres shall be rejected.

"The Operation of the Test. 10. The Brick Charge. The number of bricks per test, shall be ten for all bricks of so-called block-size, whose dimensions fall between 8 and 9 in in length, 3 and 3¾ in in breadth, and 3¾ and 4¼ in in thickness.* No brick should be selected as part of a regular test, that would be rejected by any other requirements of the specifications under which the purchase is made.

"11. Speed and Duration of Revolution. The rattler shall be rotated at a uniform rate of not less than 29.5 nor more than 30.5 rev per min, and 1800 rev shall constitute the test. A counting machine shall be attached to the rattler for counting the revolutions. A margin, not to exceed 10 rev will be allowed for stopping. Only one start and stop per test is generally acceptable. If, from accidental causes, the rattler is stopped and started more than once during a test, and the loss exceeds the maximum permissible under the specifications, the test shall be disqualified and another made.

"12. The Scales. The scales must have a capacity of not less than 300 lb, and must be sensitive to 0.5 oz, and must be tested by a standard test weight at intervals of not less than every ten tests.

"13. The Results. The loss shall be calculated in percentage of the initial weight of the brick composing the charge. In weighing the rattled brick, any piece weighing less than 1 lb shall be rejected.

"14. The Records. A complete and continuous record shall be kept of the operation of all rattlers working under these specifications. This record shall contain the following data concerning each test made: (1) The name of the person, firm or corporation furnishing each sample tested. (2) The name of the maker of the brick represented in each sample tested. (3) The name of the street, or contract, which the sample represented. (4) The brands or marks upon the bricks by which they were identified. (5) The number of bricks furnished. (6) The date on which they were received for test. (7) The date on which they were tested. (8) The drying treatment given before testing, if any. (9) The length, breadth and thickness of the bricks. (10) The collective weight of the ten large spherical shot used in making the test at the time of their last standardization. (11) The number and collective weight of the small spherical shot used in making the test, at the time of their last standardization. (12) The total weight of the shot charge, after its last standardization. (13) Certificate of the operator that he examined the condition of the machine as to staves, liner, and any other parts affecting the barrel, and found them right at the beginning of the test. (14) Certificate of the operator of the number of charges tested since the last standardization of shot charge and last renewals of stave-liners. (15) The time of the beginning and ending of each test, and the number of revolutions made by the barrel during the test, as shown by the indicator. (16) Certificate of the operator as to number of stops and starts made in each test. (17) The initial collective weight of the ten bricks composing the charge and their collective weight after rattling. (18) The loss calculated in percentage of the initial weight and the calculation itself. (19) The number of broken bricks and remarks upon the portions which were included in the final weighing. (20) General remarks upon the test and any irregularities occurring in its execution. (21) The date upon which the test was made. (22) The location of the rattler and name of the owner, upon which the test was made. (23) The cer-

*Where brick of larger or smaller sizes than the dimensions given above for blocks are to be tested, the same number of bricks per charge should be used, but allowance for the difference in size should be made in setting the limits for average and maximum rattler loss.

tificate of the operator, that the test was made under the specifications of the Am. Soc. Test. Mat., and that the record is a true record. (24) The signature of the operator or person responsible for the test. (25) The serial number of the test.

"In the event of more than one copy of the record of any test being required, they may be furnished on separate sheets, and marked duplicates, but the original record shall always be preserved intact and complete. For the convenience of the public, the accompanying blank form, which provides space for the necessary data, is furnished and its use recommended.

Report of Standard Rattler Test of Paving Brick

IDENTIFICATION DATA Serial No......

Name of the firm furnishing sample..
Name of the firm manufacturing sample..
Street or job which sample represents..
Brands or marks on the brick..
Quantity furnished.......................Drying Treatment........................
Date received.......................Date tested........................
Length.................Breadth..................Thickness..................

STANDARDIZATION DATA

Weight of Charge (After Standardization)	Condition of Lock Nuts on Staves	Condition of Scales	Number and Position of Fresh Stave-Liners	Repairs. (Note any repairs affecting the condition of the barrel)
10 Large spheres.... Small spheres. Total.........				

Number of charges tested since last inspection..

RUNNING DATA

	Time Readings			Revolution Counter Readings	Running Notes, Stops, etc
	Hours	Minutes	Seconds		
Beginning of Test.... Final Reading.......					

WEIGHTS AND CALCULATIONS

		Percentage Loss (Note: The Calculation Must Appear)
Initial Weight of Ten Bricks.......... Final Weight of Same............... Loss of Weight....................		

Number of broken bricks and remarks on same..................................

I certify that the foregoing test was made under the specifications of the American Society for Testing Materials, and is a true record.

(Signature of Tester) ....

Date.................... Location of Laboratory..............................

"Acceptance and Rejection of Material. 15. BASIS OF ACCEPTANCE OR REJECTION. Paving bricks shall not be judged for acceptance or rejection by the results of individual

tests, but by the average of not less than five tests. Where a lot of bricks fail to meet the required average, it shall be optional with the buyer, whether the bricks shall be definitely rejected or whether they may be regraded and a portion selected for further test as provided in Par. 16.

"16. RANGE OF FLUCTUATION. Some fluctuation in the results of the rattler test, both on account of variations in the bricks and in the machine used in testing, are unavoidable, and a reasonable allowance for such fluctuations should be made, wherever the standard may be fixed. In any lot of paving brick, if the loss on a test computed upon its initial weight exceeds the standard loss by more than 2%, then the portion of the lot represented by that test shall at once be resampled and three more tests executed upon it, and if any of these three tests shall again exceed by more than 2% the required standard, then that portion of the lot shall be rejected. If in any lot of brick, two or more tests exceed the permissible maximum, then the buyer may at his option reject the entire lot, even tho the average of all the tests executed may be within the required limits.

"17. FIXING OF STANDARDS. The percentage of loss which may be taken as the standard, will not be fixed in these specifications, and shall remain within the province of the contracting parties. For the information of the public, the following scale of average losses is given, representing what may be expected of tests executed under the foregoing specifications:

	General Average Loss Percent	Maximum Permissible Loss Percent
For bricks suitable for heavy traffic........	22	24
For bricks suitable for medium traffic......	24	26
For bricks suitable for light traffic..........	26	28

Which of these grades should be specified in any given district and for any given purpose is a matter wholly within the province of the buyer, and should be governed by the kind and amount of traffic to be carried, and the quality of paving bricks available.

"18. CULLING AND RETESTING. Where, under Pars. 15 and 16, a lot or portion of a lot of bricks is rejected, either by reason of failure to show a low enough average test or because of tests above the permissible maximum, the buyer may at his option permit the seller to regrade the rejected brick, separating out that portion, which he considers at fault and retaining that which he considers good. When the regrading is complete, the good portion shall be then resampled and retested, under the original conditions, and if it fails again either in average or in permissible maximum, then the buyer may definitely and finally reject the entire lot or portion under test.

"19. PAYMENT OF COST OF TESTING. Unless otherwise specified, the cost of testing the material as delivered or prepared for delivery, up to the prescribed number of tests for valid acceptance or rejection of the lot, shall be paid by the buyer. See also Par. 23. The cost of testing extra samples made necessary by the failure of the whole lot or any portion of it, shall be paid by the seller, whether the material is finally accepted or rejected.

" Visual Inspection. It shall be the right of the buyer to inspect the bricks, subsequent to their delivery at the place of use, and prior to or during laying, to cull out and reject upon the following grounds:

"20. All bricks which are broken in two or chipped in such a manner that neither wearing surface remains substantially intact, or that the lower or bearing surface is reduced in area by more than 1/5. Where bricks are rejected upon this ground, it shall be the duty of the purchaser to use them so far as practicable in obtaining the necessary half-bricks for breaking courses and making closures, instead of breaking otherwise whole and sound bricks for this purpose.

"21. All bricks which are cracked in such a degree as to produce defects such as are defined in Par. 20, either from shocks received in shipment and handling, or from defective conditions of manufacture, especially in drying, burning or cooling, unless

such cracks are plainly superficial and not such as to perceptibly weaken the resistance of the brick to its conditions of use.

"22. All bricks which are so off-size, or so misshapen, bent, twisted or kiln-marked, that they will not form a proper surface as defined by the paving specifications, or align with other bricks without making joints other than those permitted in the paving specifications.

"23. All bricks which are obviously too soft and too poorly vitrified to endure street wear. When any disagreement arises between buyer and seller under this item, it shall be the right of the buyer to make two or more rattler tests of the brick which he wishes to exclude, as provided in Par. 2, and if in either or both tests, the bricks fall beyond the maximum rattler losses permitted under the specifications, then all bricks having the same objectionable appearance may be excluded, and the seller shall pay for the cost of the test. But if under such procedure, the bricks which have been tested as objectionable, shall pass the rattler test, both tests falling within the permitted maximum, then the buyer cannot exclude the class of material represented by this test and he shall pay for the cost of the test.

"24. All bricks which differ so markedly in color from the type or average of the shipment, as to make the resultant pavement checkered or disagreeably mottled in appearance. This Section shall not be held to apply to the normal variations in color which may occur in the product of one plant among bricks which will meet the rattler test as referred to in Pars. 15, 16 and 17, but shall apply only to differences of color which imply differences in the material of which the bricks are made, or extreme differences in manufacture."

10. Cost Data on Brick

Table IV.—Production and Cost of Paving Brick in the United States

From *Mineral Resources of the United States, 1915*

Year	Quantity	Value	Average Price per Thousand
1895	381 591 000	$3 130 472	$8.20
1896	320 407 000	2 794 585	8.72
1897	435 851 000	3 582 037	8.22
1898	474 419 000	4 016 822	8.47
1899	580 751 000	4 750 424	8.18
1900	546 679 000	4 764 124	8.71
1901	605 077 000	5 484 134	9.06
1902	617 192 000	5 744 530	9.31
1903	654 499 000	6 453 849	9.86
1904	735 489 000	7 557 425	10.28
1905	665 879 000	6 703 710	10.07
1906	751 974 000	7 857 768	10.45
1907	876 245 000	9 654 282	11.02
1908	978 122 000	10 657 475	10.90
1909	1 023 654 000	11 269 586	11.01
1910	968 000 000	11 004 666	11.37
1911	948 758 000	11 115 742	11.72
1912	911 869 000	10 921 575	11.98
1913	958 680 000	12 138 221	12.66
1914	931 324 000	12 500 866	13.42
1915	953 335 000	12 230 899	12.83

CONSTRUCTION

11. Cushions

A cushion between the paving brick and the artificial foundation, unless the latter is of the proper quality of sand, has been considered necessary for two reasons: First, to offset and eliminate the unavoidable inequalities and unevennesses in the surface of the artificial or natural foundation; and

second, in order to give a uniform bearing and cushioning to, and to compensate for the inevitable inequalities in height of, the individual brick. Also it has been contended that there was a desirability for the interposition of a somewhat resilient layer between the rigid brick wearing surface and its equally rigid foundation, in order that a resiliency in the whole result might be secured to some extent at least, as well as to decrease the resonance and noise. All are not in agreement on these points and the effectiveness of the sand cushion.

Mortar Beds on top of the artificial foundation are a relatively new development in brick paving work, tho they have been used for wood blocks for many years, especially in Europe. In 1906, Baltimore laid a vitrified brick pavement on Lexington St. between Calvert and Charles Sts., using a ½-in layer of one part cement mixed with three parts sand, and since that time has laid several other streets with brick on a similar bed, altho the proportion of sand has been increased in some cases to five. In 1910, the roadways in the Penn. R. R. Terminal in New York City were similarly built with a mortar bed for the brick. Both the instances cited now show entirely satisfactory results from the use of the mortar bed. It is true that in each case, traffic conditions are peculiar. The 7% grade and the local police regulation making it a one-way street, limit the traffic on Lexington St., Baltimore, and the traffic on the Penn. R. R. Terminal roadways is preponderatingly that of rubber tired motor vehicles. Altho many other instances of the more recent use of mortar beds for brick pavements may be found, definite conclusions have not been drawn as yet. The use of mortar beds in substitution for a sand or other cushion may prove to be highly advantageous for many reasons, such as the elimination of hollow sounds or roaring in brick pavements, the successful correction of the tendency of a sand cushion to shift its place, greater ease and rapidity in construction, no increase and perhaps even a decrease in cost, and the result of an even more highly resistant surfacing. On the other hand, this substitution may result in increased resonance, increased rigidity and brittleness of surfacing, and increase in the effects of expansion and contraction. Cracking of the foundation may become apparent in the pavement when otherwise it would not be transmitted to the surfacing. See (15), (19), (22c), (30b), (31a), (32a), (32b), (35a), (35b), (43), (46), (47b), (49a), (49b), (52a) and (56).

With Sand Cushions, such as have been usually provided for brick pavements, the thickness for the cushion recommended by the National Paving Brick Manufacturers' Assn. is 1½ in after compaction. Some engineers reduce this figure going as low as 1 in, but unless the surface of the foundation is extremely and unusually even, a 1-in sand cushion is likely to prove unsatisfactory. While 1 in of sand will probably provide sufficient cushioning effect for the brick, less than 1 in will not do so. A 1-in cushion being specified and attempted, it is almost impossible to prevent the cushion having a thickness of less than 1 in at certain points, which points later prove foci of failure in the pavement surface.

It has been found, upon inspection, that under the peculiar conditions of some cases, a shifting of the sand cushion under the brick has taken place, and the brick have been in these cases left unsupported or unevenly supported in areas of the pavement. The thicker the cushion originally provided, the greater the probabilities of such possible shifting of the cushion, hence the maximum limit of 2 in. More than 2 in cannot be properly compacted. The shifting of the sand cushion is considered re-

sponsible for the objectionable hollow sound or resonance of some brick pavements.

A great deal of care, more than is usually displayed in the work of providing this cushion, is desirable. It should be of the greatest possible uniformity both as to composition and thickness. The sand should be free from pebbles and sufficiently free from loam or earthy matter to prevent its caking. See (20). It must be evenly spread and thoroly and evenly compacted. It cannot be spread properly if wet, and it cannot be evenly compacted if spread from dumped piles whose tops have been merely knocked off. A thoro raking of the cushion after spreading is desirable in order to secure an even distribution of the sand, and rolling is necessary to insure proper compaction. A template properly made and operated is then necessary for truing the surface of the cushion and securing the desirable evenness to it. Uniformity of thickness of the cushion is largely dependent upon the evenness of the surface of the foundation. The escape of the sand cushion into the joints of the artificial foundation along rails should be made impossible.

Sand Mixed with Bituminous Material is much more resilient than the sand alone. The use of this mixture may avoid some of the difficulties with sand cushions, and the thickness of the cushion might be cut down without loss of cushioning effect. Such a cushion would also be probably less likely to respond to shifting influence.

Sawdust Mixed with Bituminous Cement will form an elastic cushion, and one perhaps less expensive in certain localities than a sand mixture. The thickness necessary for cushioning effect in this case might be still further reduced. The bituminous cement might be expected to prevent the decay of the sawdust, and, if of proper quality and mixed in proper proportions, the resistance of the cushion to shifting influences would probably be at least normal.

Fibered-Asphalt Pavement might be used advantageously. Fibered-asphalt is a mixture of asphalt cement and wood fiber obtained as a by-product in the extraction of sap products from trees, the wood fibers in the process being of considerably greater length than the particles of sawdust.

The Cushion Should Always be Well Rolled. After spreading, to a slight excess in thickness, the sand and thoroly raking it, so as to secure an even disposition of it, a roller weighing from 300 to 400 lb should be drawn by hand both longitudinally and laterally or diagonally over the sand cushion. Any depressions resulting should be filled with more sand and the rolling resumed and continued until the utmost compaction of the sand is evenly secured. The surface of the sand should then be found to be slightly higher than the elevations desired for it, and it should be brought evenly to the proper height by striking off the surface with a template.

Specifications for Cushion Materials adopted at the First Conference, 1917, State Highway Engineers and Chemists, are as follows:

"The Sand shall pass a .... inch laboratory screen, and less than .... percent shall pass a 20-mesh sieve. The material removed by the elutriation test, consisting chiefly of clay and loam, shall not exceed .... percent by weight.

"The Granulated Slag shall consist of clean, sharp, gritty particles of water-cooled (insert types allowable) slag, all of which shall pass a .... inch laboratory screen."

12. Laying and Rolling the Brick

The usual practice is to lay the brick in courses at right angles with the axis of the street and on edge, so that the individual brick present to wear one of the two faces about 3½ by 8½. Exceptions to this practice

are sometimes met with at intersections where the courses in each quarter of the intersection are laid parallel to a diagonal thru the intersection with the idea of giving a better foothold to animals turning the corner or crossing the pavement. It has been suggested that no real necessity exists, when the pavement is properly grouted with cement mortar, for courses across the roadway and that the avoidance of gores in the surface of curved roadways may be had by laying the brick lengthwise. This has been successfully done in some cases. One of the difficulties in laying a brick pavement arises from the desirability of keeping the courses reasonably straight, for appearance's sake, and the joints between the courses and between the individual brick uniform, so as to permit evenness in their filling. The usual variation from the straight line allowable in the courses is within 2 in, for the attainment of its appearance, but it is not desirable to have the brick more tightly jammed together at some points than at others. Too wide a joint is obviously undesirable and too narrow a one is equally so because of the difficulties of properly filling excessively narrow joints. Different devices have been adopted for keeping the bricks at a certain distance from each other in the shape of letters or raised projections on the brick. The more recent device of lugs seems to give the best results and to provide for a proper width of joint.

Inspection of Brick During Laying. As brick samples to be tested are usually taken in the proportion of one sample for each 1000 brick in the shipment, it is evident that there is a considerable opportunity for individual brick of varying quality passing the tests. The presence of such brick in the pavement may result in uneven wear and the production of serious holes in the surface. It is frequently the practice, after the brick have been laid in the pavement, but before they are grouted, to sprinkle the pavement with water. The eye is then able to note quickly any great variation in the imperviousness of the individual brick, and the removal and replacement of these can quickly and readily be made. A very common practice under recent specifications consists of inspecting the brick after laying, but before filling the joints, and turning over, with the aid of a pair of tongs, those brick which have been placed in the pavement with an objectionable face up. This is bad practice, because the sand cushion is disturbed in the process. The best practice is to place the brick for the pavers so that they will invariably lay the brick with its best face up.

Bricks Laid on the Flat Side. A recent experiment has been made in a number of instances by laying the brick on their flat or larger side, and in courses as above. This departure gives the advantage of requiring slightly less brick per square yard than where they are laid on edge, tho it reduces the resistance of the pavement to sustaining heavy loads, and there is more liability of the brick becoming cross-broken thru the reduction in depth. There seems to be no good reason why the practice of laying the brick on their flat sides should not be followed where the loads coming on the pavement are only moderately heavy and where a proper foundation and cushion have been provided. The reduction in first cost per square yard by laying the brick flatwise would average between 5 and 10 cents per sq yd. Where the traffic is expected to be light, the laying of the brick flatwise may have another advantage, if a natural foundation of suitable sand is expected to be sufficient, in that the greater bearing area of the brick laid flatwise should reduce a tendency of the individual brick laid edgewise to become driven down under traffic. See (17), (30a), (30e), (54a) and (57).

The Brick Should be Rolled subsequent to laying and after the surface of the partly completed pavement has been swept clean, inspected for defects and the latter corrected. Disturbance of the brick after rolling should be avoided just as far as possible. The roller for the brick should be one that can be easily and rapidly managed and should weigh between 4 and 5 tons. In order to offset any tendency of the brick to careen under the roller, the number of forward trips of the latter over any part of the pavement should be equalled by the number of backward trips over the same part. The rolling should proceed beginning at each edge of the pavement along the curb and working toward the center of the roadway; then cross rolling at angles of about 45° each way from the center line; again rolling lengthwise and again cross rolling as before, continuing this process until the brick are firmly fixed in the cushion, the surface of the pavement even at the elevations intended and any inequalities of the cushion or in the height of the brick ironed out and the cushion more or less pushed up into the joints between the brick. This condition is always found in the case of properly rolled brick pavements, the rising of the cushion into the joints being somewhat uneven, in an amount varying from ½ to 1 in according to the conditions. Rolling with a horse roller or too heavy a steam roller can but result unsuccessfully, as under such rollers, the brick will invariably creep under the horizontal strains. Again, such rollers cause the brick to tilt as they are passed over and become displaced to an extent that the surface of the pavement becomes rougher the more it is rolled. Further, under excessive weights of roller, the brick are so pushed down that they rebound when the weight passes off and compaction to the desired degree is never secured.

After the brick are properly rolled and fixed, those that have broken under the roller should be removed and replaced, the new brick being carefully tamped into place. In places where the use of the roller is impracticable, such as around manholes or close to the curbs, the brick should be brought to a true surface and made firm by means of ramming. For this purpose, a rammer should weigh from 80 to 100 lb and its blows should not fall directly upon the brick but should be transmitted thru a board laid on their surface.

13. Joint Filling

The Filler Recommended by the National Paving Brick Manufacturers' Assn. is Cement Grout, except for expansion joints. The cement filler when properly applied unquestionably gives additional strength to the pavement by uniting the individual brick together into a strongly coherent mass, and thus enabling the distribution of the strains over a larger area. It gives better protection to the edges of the individual brick and against their tendency to spall at the edges under blows. It aids toward uniformity of wear and results in a smoother surface for the pavement. Its disadvantages are the mechanical difficulties of properly applying a cement filler and of having this sort of filling sufficiently uniform thruout the paved area. The cement filler is rigid and increases, rather than decreases, the rigidity of the pavement and the effects of expansion and contraction. On steep grades, the cement grouted brick pavement may be objectionably slippery, especially in certain kinds of weather. It is objected to frequently as producing a more noisy pavement than a bituminous filler, but this complaint is disputed (see Art. 2).

The Relative Strength of Cement Grout Fillers made with different

proportions of cement and sand is indicated by some tests made in connection with some brick pavement work in King County, Wash.

Allen (11) states that these tests were made "of sections of brick pavement constructed as beams 12 in wide and spanning 42 in between supports, chiefly to study the efficiency of cement joints mixed 1 : 1, 1 : 1½, and 1 : 2. In making these beams, the methods of laying and of mixing and brushing in grout commonly used in county work were those employed. Each beam was tested on a 42 in span, center to center, and the load applied at the center of the span. The beams were placed in the testing machine with the wearing surface up, on which surface the load was applied. The ends of the beams rested on rocker supports, and plaster of Paris was used to secure an even bearing at all contact points. A deflectometer was used to record the amount of deflection in the beam at the instant of failure. With the 1 : 1 grout the plane of failure cut right across one brick and for the rest of the way was thru the bond. In one instance a lug was sheared off. With the 1 : 1½ grout the failure in one case was across two brick and the rest of the way thru the bond. In the second case the failure was thru the bond all of the way. With the 1 : 2 grout the failure was entirely thru the bond in each instance. In no instance was the failure thru the grout; it was always thru the bond, across the grout or thru the brick. The results of these beam tests are given in Table V:

Table V

Beam No.	Dimensions of Beams			Deflection at Max. Load Ins	Maximum Load Pounds	Modulus of Rupture, lb per sq in	Cement Sand Mixture	Number of Bricks Ruptured
	Hgt. Ins	Width Ins	Span Ins					
1..........	4	12	42	0.037	3290	1080	1:1	1
2..........	4	12	42	0.038	3000	984	1:1	1
3..........	4	12	42	0.043	3015	989	1:1	1
Average....	..	..	..	0.039	....	1018	.....	..
4..........	4	12	42	0.026	2800	918	1:1½	None
5..........	4	12	42	0.020	2615	857	1:1½	2
Average....	..	..	..	0.023	....	887	.....	..
6..........	4	12	42	0.030	2410	790	1:2	None
7..........	4	12	42	0.034	2350	771	1:2	None
Average....	..	..	..	0.032	....	780	.....	....

The Application of the Cement Filler is one of the most important features of proper brick pavement construction and should have the utmost care. The cement filler should be mechanically mixed and mechanically applied, if possible. While in the application of the cement filler, usually more incorrect and varied means or methods are resorted to than in any other portion of the work, the proper method is a simple one and easily followed. Clean sand, first-class Portland cement and a proper proportion of water are necessary. Too much water is as objectionable as too little, owing to the greater tendency toward segregation of the sand and cement when water is used in excess. Too little water does not provide the fluidity necessary for the mixture to properly enter the joints. A good method for applying the cement filler to brick pavements, which method has been developed thru practical work, has been carefully described in the publications of the National Paving Brick Manufacturers' Assn. as follows:

"The sand should be dry. The mixture, not exceeding 1/3 bu of the sand, together with a like amount of cement, shall be placed in the box and mixed dry, until the mass assumes an even and unbroken shade of color. Then water shall be added to form a liquid mixture of the consistency of thin cream. From the time the water is applied until the last drop is removed and floated into the joints of the brick pavement,

the mixture must be kept in constant motion. The mixture shall be removed from the box to the street surface with a scoop shovel, all the while being stirred in the box as the same is being thus emptied. The box for this purpose shall be 3½ to 4 ft long, 27 to 30 in wide, and 14 in deep, resting on legs of different lengths, so that the mixture will readily flow to the lower corner of the box, which should be from 8 to 10 in above the pavement. This mixture, from the moment it touches the brick, shall be thoroly swept into the joints. Two such boxes shall be provided in case the street is 20 ft or less in width; exceeding 20 ft in width, three boxes should be used.

"The work of filling should thus be carried forward in line until an advance of 15 to 20 yd has been made, when the same force and appliances shall be turned back and cover the same space in like manner, except to make the proportions ⅔ Portland cement, and ⅓ sand. To avoid the possibility of the thickening at any point, there should be a man with a sprinkling can, the head perforated with small holes, sprinkling gently the surface ahead of the sweeper. Within ½ to ¾ hr after this last coat is applied, and the grout between the joints has fully subsided and the initial set is taking place, the whole surface must be slightly sprinkled and all surplus mixture left on the tops of the brick swept into the joints, bringing them up flush and full. After the joints are thus filled flush with the top of the brick and sufficient time for evaporation or initial hardening has taken place, so that the coating of sand will not absorb any moisture from the cement mixture, ½ in of sand shall be spread over the whole surface, and in case the work is subjected to a hot summer sun, an occasional sprinkling sufficient to dampen the sand should follow for 2 or 3 days.

"The first application should be thin in order that it may flow to the depth of the joints of the brick, thereby insuring a substantial bond, and should be kept in constant motion while being applied, otherwise the sand will settle, leaving water and cement, instead of water, sand and cement. The water and cement would not be objectionable, but the sand by itself is wholly so.

"It must also be mixed in small quantities, as it is next to impossible to keep the sand in suspension when more than a common water pail of each, sand and cement, is used, and unless it is deposited upon the pavement with the sand in combination with the solution, the cement and water will get into the lower portion of the joints between the bricks, and the sand without the cement in the upper portion. It is preferable, after the sand and cement have been mixed dry, to apply sufficient water and mix slowly, first to a good mortar, then add sufficient water to bring the mortar to the required consistency. By this method a more thoro adhesion of the cement to the sand can be obtained."

Specifications for Grouting Sand adopted at the First Conference, 1917, State Highway Engineers and Chemists are as follows:

"The sand shall consist of clean, hard, durable, uncoated particles, preferably siliceous, free from lumps of clay and all organic matter.

"**Grading.** It shall be well graded from coarse to fine and, when tested by means of laboratory screens, shall meet the following requirements:

Passing ....* mesh sieve................not less than ....**%.
Passing 100-mesh sieve................not more than ....%.
Not more than ....% by weight shall be removed by the elutriation test.

"**Mortar Strength Test.** When the sand is mixed with Portland cement in the proportions of 1 part of cement to 3 parts of sand by weight, according to standard methods of making 1 : 3 mortar briquets, the resulting mortar at the age of 7 and 28 days shall have a tensile strength of at least .... ***percent of that developed in the same time by mortar of the same proportions and consistency, made of the same cement and Ottawa sand. Preliminary acceptance samples shall be subjected to both 7 and 28-day tests, and acceptance based thereupon. Samples tested during the progress of the work will be accepted on the basis of the 7-day test."

The Following Practices Often Observed are Erroneous and should be avoided: The filler is applied from the mixing box with a bucket and

*It is recommended that a 10-mesh sieve be specified.
**Ninety-five percent is recommended for this purpose.
***It is recommended that 65 percent be the minimum allowable strength ratio; and that in localities where practicable, a higher strength ratio be specified.

carried to the point of application. Settlement of the sand to the bottom of the bucket invariably occurs, as it also does when too great a time elapses between the mixing in the box and the turning of the box or the emptying of the box, especially if the stirring is not continuous. Water, applied to the dry mixture before the latter has reached an even shade, interferes with the proper adhesion of the particles. Remedying an improper thickness of mixture by throwing it upon the pavement and then adding more water serves only to float the cement away from the sand. Applying the mixture to the pavement faster than it can be swept in results in lack of uniformity and dissatisfaction. If the quantity of mixture applied requires a portion of it to be swept to a considerable distance in order for it to disappear in the joints, the last that goes in will be little better than pure sand. By the proper method, the mixture in the box is drawn to the upper portion of the box by two workmen with hoes, and with the natural backward flow, the mixture is equally agitated. The lift of the scoop, with the box sufficiently adjacent to the joints to be filled, will allow a mixture in proper condition to strike the surface of the brick and to immediately enter the joints, thus more nearly insuring the filler in place in its proper proportion than by any other method. By the use of a sufficient number of boxes and a systematized force of workmen, the greatest economy to the contractor is secured and the possibilities of the cement filler attained.

Dampening the Brick ahead of the application of the filler is necessary in almost all cases in order that proper adhesion of the filler to the brick shall be had. The brick must be uniformly dampened and not excessively wetted. The use of a hose, especially one throwing a stream of water, is objectionable for this purpose. It may be possible to use a hose satisfactorily if it is supplied with a nozzle which will result in a thin spray of water being thrown thru it. Even then, the use of the hose tends to result in the application of too much water. A sprinkling can with what is known as a rose head, that is, a head with many small perforations in it over the spout, and the careful application of the water by hand should generally be required. See (30d).

Bituminous Fillers reduce the necessity of expansion joints in the pavement, and permit a certain flexibility in the pavement which practically obliterates any cracking of the brick thru contraction or expansion. They are usually applied with greater ease and uniformity than in the case of a cement filler. They leave a surface to the pavement which is less smooth and consequently less slippery. Another advantage claimed for the bituminous filler is the possibility when once cracked, of its reunion, which is impossible in a cement filler. Their disadvantages are that the proper kind of bituminous filler is usually difficult to obtain for any specific case; that is, bituminous cement, with the proper quality of adhesiveness in order to stick the brick together, is generally quite susceptible to extremes of heat and cold, becoming fluid and running out of the joints on grades in the warm sun, and becoming brittle and breaking in the joints in cold weather. Any lack of imperviousness in the joints, thru the breaking of the filler, will result disastrously to the cushion and to the pavement. Further, bituminous fillers fail to support the edges of the brick sufficiently to prevent spalling, and it is but a short time after a brick pavement with bituminous joints is completed before the brick begin to wear into convex form on their upper surface, thus increasing the difficulties of keeping the pavement thoroly clean, increasing the noise from the surface, and damaging its appearance.

14. Expansion Joints

Expansion joints should be provided, along the curbs at least, in all brick pavements. In the case of cement grouted brick pavements, greater provision for expansion joints must be made than in the case of brick pavements with bituminous joints. A general practice, where the brick are laid in courses across the roadway, is to place a board of a proper thickness next to the curb before the brick are laid and then, after the joint filling of the pavement is completed, to withdraw the board and fill the space left with a bituminous cement. The thickness of the board to be used will depend upon the width of the street, and the following thicknesses are those recommended by the National Paving Brick Manufacturers' Assn.: Width up to 20 ft, ½ in along each curb; 20 to 30 ft, 3/4 in along each curb; 30 ft or over, 1 in along each curb.

Distribution of Total Thickness of Bituminous Filler. A better practice is to distribute the thickness of this expansion joint over three or four joints in courses of brick laid parallel to the curb and against which longitudinal courses, the courses of the brick across the roadway abut. This is especially so in the cases of the wider expansion joints required. There is less likelihood of the several thinner joints being rendered ineffective by sand, gravel or other debris from the roadway, than in the case of one wide joint.

Expansion Joints Across the Street are now generally omitted and are recommended to be always omitted by the latest specifications of the National Paving Brick Manufacturers' Assn. It is questionable if in the cases of wide brick pavements, this reçommendation should be followed for the reason that, on some streets laid in recent years under the modern specifications and the most careful inspection, it has been found that apparently the strains caused by expansion in the cement grouted brick pavements have not all been transmitted to the expansion joints on the side and there taken up without causing some shattering of the brick in the pavement apparently thru excessive pressure on these brick. In the cases referred to, the streets were 40 ft or more between curbs and no street car tracks were in the area of the pavement. The only expansion joints were the ones provided along the curbs. The crushing strength of the brick, altho normal at least, was apparently insufficient to resist the strains, caused by expansion or contraction, which passed thru them from large adjacent areas. Apparently expansion joints at intervals of, say, 100 ft across the street would have obviated the difficulty.

Transverse Expansion Joint for Monolithic Brick Paving (48a). "The transverse joint has a special feature that is original with the writer. When the location of the joint is made, a trench 2 ft wide, 12 in on each side of the location, is cut to a depth of 3 in. This trench is filled level full with concrete and covered with building paper. The concrete base is then placed and shaped over this support. The joint is afterward cut thru to the paper and filled with sand, as above described, care being taken not to break the paper. This gives a solid base for the joint to rest upon, and on which it may freely move. This prevents settling of the base, which might be caused from water seeping thru and softening the subgrade at these joints. Another special feature of the joint is the laying of the brick as headers, with the prepared joint between the heads. Laying the brick as headers at the end of all street intersections, which takes the place of marginal curbing, is another special feature. The theory for this arrangement is that the weakest point in the pavement, and the point most exposed to traffic, is at the joints and at the end of the intersections. By laying the brick as headers a longer bearing is given for resisting the impact from vehicles and from horses' hoofs."

Precautions in Construction of Expansion Joints. Great care must be taken with the expansion joints in order that there may be no hindrance

to their acting as such. Sand or other incompressible material of any kind must not be allowed to enter them and the bituminous cement must be of the proper quality to permit the movement of the brick adjacent without separation either from the brick or in the bituminous cement itself. Any such separation will permit the entrance of foreign material and ultimately destroy the expansibility of the joint. The bituminous cement must not be so susceptible to heat as to run out of the joints in hot weather nor so susceptible to cold as to permit the separation of the brick from the bituminous cement or the cracking open of the bituminous filler in the joints during the contraction of the pavement. If the bituminous cement is likely to be covered with water for considerable periods at certain seasons, its good qualities must not be affected by this immersion, and if the expansion joints are so situated as to receive the shocks of traffic, it must not at any time become brittle enough to be broken out of the joints by the traffic. The main objections to expansion joints in the pavement across the roadway are their cost and their interference with uniformity of the surface exposed to traffic and the resulting ridge or depression which will occur at them and tend toward uneven wear.

Where Car Tracks Are to Exist within the area of the brick pavement, an expansion joint should be provided along both sides of each rail. It may be placed next to the rail or rail filler block, or it may be installed along the side of the runner, block laid lengthwise with the rail, in case the latter is used.

15. Specifications for Construction

Fundamental Principles adopted in 1917 by the Spec. Com. Mat. Road Cons., Am. Soc. C. E. (12b).

"**Artificial Foundation.** Owing to the inelastic nature of brick and slag block pavements, the surface of the wearing course must be smooth and true to contour, to insure ease of traction, comfortable riding, and the integrity of the surface, particularly where cement joints are used. Special care, therefore, should be taken to provide a concrete foundation of ample strength and with a surface parallel with that of the wearing course. The minimum of 4 in for the thickness of the artificial foundation should be used only when the brick or blocks are bedded in cement mortar on a concrete foundation resulting in a monolithic pavement approximately 8 in in thickness, or when the natural foundation affords good drainage and is firm and unyielding. There may be conditions under which the concrete foundation can be entirely dispensed with, but this is only justified where, owing to the low first cost of the brick, exceptionally good bearing qualities of the soil, light traffic, and lack of funds to provide a more substantial road surface, brick laid with sand joints and without an artificial foundation may be used as the first step in road improvement. If the roadway is not kept clean, the material which accumulates on the surface of the wearing course will protect it from injury, and its function will then be simply to provide a foundation for an earth road.

"**Cushion Course.** The function of the cushion between the brick or block and the artificial foundation of concrete is to give resiliency to the wearing course and to allow for irregularities in the surface of the concrete and for unavoidable variations in the depth of the brick or block. If the surface of the concrete foundation is made true to the adopted cross-section, as the variation of the depth of the brick or block decreases, the thickness of the sand cushion may be correspondingly decreased. The desirable resiliency will be secured by a sand cushion 1 in, or even slightly less, in depth, provided that depth is uniform, and if the surface of the concrete foundation is truly parallel with the finished pavement; and, if the variation in the depth of the brick or block does not exceed ⅛ in, the thickness of the sand cushion can safely be reduced to ¾ in. In a number of brick pavements recently laid, the cushion course has been dispensed with entirely, the brick having been bedded in cement mortar spread over the concrete foundation. This results in a monolithic structure less capable of absorb-

ing shock than is the case where a sand or bituminous cushion is interposed between the wearing surface and the foundation, and the joints are filled with a bituminous filler. A cushion course composed of sand or stone chips and a bituminous cement from 1/4 to 1/2 in in thickness may be substituted for sand or cement mortar, provided the surface of the concrete foundation is made sufficiently smooth and regular in contour.

"Construction. The brick or block should be laid in straight courses at right angles to the axis of the roadway, altho at intersections they may advantageously be laid in diagonal courses arranged so that traffic turning any of the corners will move across and not along the continuous joints. They should be laid so that the joints shall be uniform in width and of sufficient width only to permit the filler to reach the bottom of the joints. Lug bricks have the advantage of insuring such uniform joints, with ordinary care in laying. If a sand cushion is used great care should be taken to avoid any disturbance of the surface of the cushion after it shall have been brought to true grade by using a template. If bedded in a mortar or bituminous cushion, the brick or block should be bedded so that the surface shall be as true as possible. In all cases the brick after being laid should be brought to a true and even surface by the use of a roller."

Specifications for Brick Pavement with Sand Cushion as adopted in 1916 by the Am. Soc. Mun. Imp. are as follows, except that the description of the rattler test (see Art. 9) is omitted.

"Character of Brick. All brick must be of the sizes commercially known as paving brick the widths of which must not vary more than 1/8 in. They must be thoroly annealed, tough and durable, regular in size, shape and evenly burned. When broken, the brick shall show a dense, stone-like body, free from lime, air-pockets, cracks or marked laminations. They must not be fire flashed, smoked or treated in any manner tending to give artificially a uniform color outside. Kiln marks must not exceed 3/16 in one from another, and one edge at least shall show but slight kiln marks. All brick so distorted in burning as to lay unevenly in the pavement shall be rejected.

"The STANDARD SIZE of paving brick shall be 3 1/2 in in width, 4 in in depth, and 8 1/2 in in length. They shall not vary from these dimensions to exceed 1/8 in in width and depth, and not more than 1/2 in in length. If the edges of the brick are rounded the radius shall not exceed 3/16 in. Only brick with four raised lugs on one side not to exceed 1/4 in nor less than 1/8 in in height shall be used. No one lug shall exceed 1/2 in in area.

"Inspection of Brick. All brick shall be subject to thoro inspection before and after laying and rolling, and all rejected material shall be immediately removed from the street. Factory inspection of brick, including the rattler test, shall be made if, in the judgment of the engineer, it be expedient. This test and inspection, however, in no wise prevent further tests and inspection of the brick after they have been received upon the improvement, if in the judgment of the engineer such is warranted.

"Delivery of Brick. The brick shall be hauled and carefully unloaded by hand without spalling or otherwise damaging the brick, and neatly piled on the walks or outside of the curbs before the grading is finished, and in laying be carried from there to the pavement.

"Rattler Test for Block Size. The brick shall not lose of their weight more than 22% after being submitted to the following tests, provided, however, that brick from any one factory and used in any one improvement shall not vary more than 8 points. Samples of brick of uniform shape and appearance shall be taken from each car tested, estimated at 10 000 brick. Brick having a defect, that would cull them, shall not be used. Three grades of samples shall be tested, one of the softest, one of the medium and one of the hardest burned. If all of the tests over-run the above percentage of loss, the car shall be rejected. If one or two of the tests over-run, another test of said grade or grades shall be made. Should only one of these tests over-run the specified percentages of loss, the contractor may cull said grade, provided they do not exceed 10% of the amount of brick in the car, and deliver the balance on the improvement. Otherwise the whole car will be rejected. In order to prevent the continued shipments of inferior brick, only two cars to two separate shipments of any make of brick will be tested. Should they fail to meet the requirements stated above said make of brick will be rejected for this improvement.

"NUMBER AND CONDITION OF BRICK. Ten paving brick shall constitute the number to be used in a single test. The brick shall be thoroly dried for at least 3 hr in a temperature of 38° C (100° F) before testing.

"TESTS BEFORE UNLOADING. The contractor shall notify the proper city official of the location and car number of each carload of brick received, so that samples, if deemed necessary, may be taken and tested by the city, and no brick shall be delivered on or adjacent to any improvement on which brick are to be used until a written statement has been received from the Engineer or his authorized representative, that they have been superficially inspected or have passed the required tests. Decision relative to each carload will be made within 24 hr of notice. Permission to deliver brick on the line of work shall not be considered a final acceptance in any respect.

"Foundation. The cement used shall conform to the requirements specified. The fine aggregate shall consist of any material of siliceous or igneous origin, free from mica in excess of 5%, and other impurities, uniformly graded, the particles ranging in size from ¼ in to that which will pass a 100-mesh sieve. The coarse aggregate shall be sound gravel, broken stone or slag, having a specific gravity of not less than 2.6. It shall be free from all foreign matter, uniformly graded, and shall range in size from ¼ in up, the largest particles not to exceed in any dimension one-half the thickness of the concrete in place.

"In preparing the concrete, the cement and aggregate shall be measured separately and then mixed in such proportions that the resulting concrete shall contain fine aggregate amounting to one-half of the volume of the coarse aggregate, and that 7 cu ft of concrete in place will contain 94 lb of cement. The ingredients of the concrete shall be thoroly mixed, sufficient water being added to obtain the desired consistency, and the mixing continued until the materials are uniformly distributed, and each particle of the fine aggregate is thoroly coated with cement, and each particle of the coarse aggregate is thoroly coated with mortar. When a mechanical concrete mixer is used, the materials must be proportioned dry, and then deposited in the mixer all at the same time. The mixer must produce a concrete of uniform consistency and color, with the stones thoroly mixed with water, sand and cement. The materials shall be mixed wet enough to produce a concrete of a consistency that will flush readily under light tamping, but which can be handled without causing a separation of the coarse aggregate from the mortar. Retempering, that is, remixing with additional water, mortar or concrete that has partially hardened, will not be permitted.

"The concrete shall be deposited in a layer on the subgrade in such quantities that, after being thoroly rammed in place, it will be of the required thickness, and the upper surface shall be true, uniform and parallel with the surface of the finished pavement. In conveying the concrete from the place of mixing to the place of deposit, the operation must be conducted in such a manner that no mortar will be lost and the concrete must be so handled that the foundation will be of uniform composition thruout, showing no excess nor lack of mortar in any place.

"The foundation shall be 6 in in thickness, with its upper surface finished parallel to and 5½ in below the grade of the finished pavement.

"When complete, the foundation shall be kept moist for not less than 2 days and it shall be protected from traffic until the concrete has thoroly set.

"No concrete shall be mixed while the air temperature is below 0° C (32° F), and in no case shall any material containing frost be used, and if this temperature is reached at any time before the foundation shall have been thoroly set, it shall be immediately provided with such covering as will protect it from all damage. In no event shall a concrete foundation be laid on a frozen subgrade.

"Sand Cushion. Over the foundation, which must be thoroly cleaned, shall be spread to a uniform depth of 1½ in, after rolling, a cushion of clean, sharp sand, free from foreign matter except that it may contain not to exceed 5% of loam. The sand must be fairly well graded from ¼ in to that which will be retained on a 50-mesh sieve. The word sand includes broken stone or slag meeting the specified grading. The cushion shall be carefully shaped to a true cross-section of the roadway by means of a template having a steel faced edge, covering at least one-half the width of the brick work, and so fitted with rollers as to be easily drawn on the curb and guide timbers or rail.

"The TEMPLATE shall be built in substantial accordance with plan accompanying these specifications.

"GUIDE TIMBERS shall be 1½ by 4 in by 16 ft, dressed on two sides, laid to a true surface in the center of the street, and also next to the curb if the curb cannot be used.

"Before SHAPING THE CUSHION a ½ in strip shall be laid on the curb, and guide timbers, or rail, and the template drawn over the same, after which the ½ in strip shall be removed, the cushion slightly moistened and rolled over its entire surface with a hand roller. The roller shall not be less than 36 in in diameter, 24 in in width, and shall weigh not less than 10 lb per in in width, and have a handle 12 ft in length. After rolling, the template shall be drawn over the curb and guide timbers or rail, to complete the cushion. The cushion shall be prepared at least 50 ft in advance of the brick laying.

"**Laying of the Brick.** The brick shall be laid in straight lines on edge, at right angles to the curb. At intersections, they shall be laid as directed. Brick shall be laid with the lug sides all in the same direction. Brick must be placed close together, both ends and sides, breaking joints at least 3 in. At every fourth course, the brick shall be driven together to secure tight joints and straight courses and all thick brick shall be removed. Brick shall be used with the best edge up. Broken, chipped or warped brick, not suitable to lay as a whole, may be used for batting. When any section shall contain more than 10% of culls, the brick shall be taken up and the cushion adjusted. Brick shall be laid from curb to curb, or car track to curb. No bats or broken brick shall be used except at curbs or at street-car tracks. Batting for closures shall immediately follow the laying. Joints shall be cut square with the top and sides of the brick. All joints must be kept clean and open to the bottom until filled as specified.

"**Street-Car Tracks.** Along the street-car tracks the brick must not be laid within ¼ in of the rail, and when rolled shall be ¼ in below the top of the rail. The space between the web of the rail and the brick shall be filled with cement mortar, consisting of 2 parts sand and 1 part Portland cement. The mortar shall be in proper condition and the edge constructed to a straight line before the brick are laid.

"**Expansion Joints for Cement Grout Filler.** Expansion joints shall be placed parallel with and at each of the curb lines, and shall be 1½ in in width. The joints shall be made by placing together on edge, parallel with the curb, two wedge-shaped strips 6 in in width, and dressed on two faces. The strip next to the curb shall be 1 in wide on top, beveled to a thickness of ½ in at the bottom, and the strip next to the brick shall be of the same dimensions and placed in a reverse position. The brick shall be laid lightly against said strips. Soon after the pavement has been grouted and the cement filler has set, and the pavement is in all other respects finished, the strips shall be removed, the joints thoroly cleaned out, and immediately completely filled with a bituminous filler composed of a material which, when penetrated by a No. 2 needle under a weight of 200 g for 1 min at a temperature of 0° C (32° F), will have a penetration of not less than 20, and when penetrated by a No. 2 needle under 50 g for 5 sec at a temperature of 46° C (115° F), will not have a penetration of over 100. A premolded expansion strip made of a material unaffected by the action of water or street liquids may be used along each curb line, if it meets all the requirements for the joint filler herein specified. These strips shall not be less than ¾ in in width for a 30 ft street or under, increasing proportionately to 1½ in in width for a 50-ft street or over.

"**Rolling.** After the brick in the pavement have been passed for rolling and the surface swept clean, the pavement shall be rolled with a roller weighing not less than 3 nor more than 5 tons, in the following manner: The brick next the curb shall be tamped with a hard wood tamper, to the proper grade. The rolling shall then commence near the curb at a very slow pace, and continue back and forth toward the center, until the center of the street is reached, then, passing to the opposite curb, it shall be repeated in the same manner to the center of the street. After this first passing of the roller the pace may be quickened and the rolling continued until the brick pavement has a smooth surface. The pavement shall then be rolled transversely at an angle of 45° from curb to curb, repeating the rolling in the opposite 45° direction. Before and after this transverse rolling has taken place, all broken or injured brick must be taken up and replaced with perfect ones. The substitute brick must be brought to the true surface by tamping. After final rolling the pavement shall be tested with a 10 ft straight-edge, laid parallel with the curb, and any depression exceeding ¼ in must be taken out. If necessary, the pavement shall be again rolled.

"**Portland Cement Grout Filler.** The filler shall be composed of 1 part each of fine, clean, sharp sand and Portland cement.

"The cement shall meet the requirements of the standard specifications for Portland cement of the Am. Soc. Test. Mat., adopted August 16, 1909, with subsequent amendments. The sand shall be clean and sharp, fairly well graded from that passing a 20-mesh sieve to that retained on a 100-mesh sieve. Sand shall be measured in a box having the same cubical contents as 1 sack of cement.

"Before any grouting is done, a sufficient amount of cement and an equal amount of sand to complete the work prepared for grouting at that time, but not to exceed 2 hours' run shall be thoroly mixed dry until the mass assumes a uniform color. From this mixture an amount not exceeding 2 cu ft shall be taken and placed in the grouting box and enough clean water added to obtain a grout that will penetrate to the bottom of the brick. From the time the water is applied until all is removed and floated into the joints of the pavement, the mixture must be kept in constant motion. A mechanical mixer approved by the Engineer that will meet these requirements may be used after the dry mixture of sand and cement has been made. Before the grout is applied the brick shall be thoroly wet by being gently sprayed. The water shall be added to this dry mixture in a box preferably about 4 ft 8 in long, 30 in wide, and 14 in deep, resting on legs of different lengths, so that the mixture will rapidly flow to the lower corner of the box, the bottom of which shall be about 3 in above the pavement. One box shall be used for each 14 ft in width of roadway, and at least two boxes must be used in all cases.

"The grout shall be removed from the box with scoop shovels and applied to the brick in front of the sweepers, who shall rapidly sweep it lengthwise of the brick into the unfilled joints, until the joints are filled to within not more than ½ in of the top of the brick. After the grout has had a chance to settle into the joint and before the initial set develops, the balance of every joint shall be filled with a thicker grout, and, if necessary, refilled, until the joints remain full to the top. After this application has had time to settle and before the initial set takes place, the pavement shall be finished to a smooth surface with a squeegee or wooden scraper having a rubber edge, which shall be worked over the brick at an angle with the brick.

"When completed and the cement has received its initial set, the pavement shall be covered with a ½ in layer of sand, which shall be frequently sprinkled in warm weather. No travel shall be permitted on the pavement for a period of at least 7 days after grouting, or longer, as the Engineer may require on account of weather conditions. Ample barricades and watchmen shall be provided by the contractor for the proper protection to the grouting.

"**Coal Tar Paving Pitch Filler.** The joints or spaces between the bricks, and those between the bricks and the curb, railroad tracks, around manholes, etc, shall be filled with coal tar paving pitch, which shall comply with the following requirements:

"Physical Properties. When in place in the pavement, it shall be of such character that it will adhere firmly to the paving brick and to the curb, and shall be sufficiently plastic to allow for the contraction and expansion in the pavement without developing cracks in the joints. The filler shall be such that it retain its consistency under extreme temperature. It shall be proof against action by water and all acids and alkalies to which the pavement may be exposed. The free carbon shall not be less than 25 nor more than 40%. The specific gravity shall not be less than 1.23 nor more than 1.30 at 15.5° C (60° F). It shall have a melting point varying not more than 8° from 57° C (5° from 135° F), determined by the cube method.

"Methods of Use. The filler shall be heated and poured into the joints to the full depth thereof, at a temperature of not less than 149° C (300° F), nor greater than 177° C (350° F). All joints shall be completely filled at the top. The top dressing of sand shall be spread over the pavement immediately after the filler is applied and while it is still soft. In cold weather the sand shall be heated so as to readily bond with the pitch. Extra care shall be used at the gutters and around catch basins, etc, to effectually prevent the leakage of water into the sub-roadway.

"**Asphalt Filler.** The interstices of the brick shall be completely filled with an asphalt filler heated to a temperature of not less than 177° C (350° F) nor more than 232° C (450° F). This asphalt filler shall not contain pitch nor any part of coal tar. It shall contain at least 98% of bitumen soluble in carbon bisulphide. It shall remain pliable at all temperatures to which it may be subjected as a street paving filler; it shall

be absolutely proof against water and street liquids; it shall firmly adhere to the brick and be pliable rather than rigid. The penetration shall conform to the following:

No. 2 needle, 5 sec, 100 g at 25° C (77° F), 25 to 60.
No. 2 needle, 1 min, 200 g at 0° C (32° F), not below 25.
No. 2 needle, 5 sec, 20 g at 46° C (115° F), not above 110.

Care shall be exercised to completely fill all openings around street structures and the street shall not be used for traffic until the filler is completely set. A top dressing of sand shall be spread immediately after the filler is applied and while it is still soft.

"Maintenance. The period of guaranty shall be 5 years. During the period of guaranty, whenever the surface of a vitrified brick pavement becomes uneven, holding water ¼ in or more in depth in a distance of 4 ft or less, or when the pavement has settled over trenches existing previous to the completion of the pavement, then the brick shall be taken up and relaid to proper crown and grade. Any brick which may be found soft, unsound, broken or disintegrated, and all portions of the pavement which may have become rough by reason of the chipping or breaking of the edges of the brick, so as to produce joints exceeding ½ in at a point ¼ in below the surface of the brick, shall be removed, and properly replaced with sound material.

"Note. All castings for manholes, catchbasins, etc, shall not be imbedded in the concrete foundation. They shall be made to rest on top of the foundation to allow the pavement to expand uniformly, thereby avoiding the cracking and crushing of the brick.

"Note to Engineer: Where medium or light traffic or other conditions exist, which, in the opinion of the Engineer, do not require a brick capable of giving an abrasive loss of only 22%, brick of a quality which will give a loss of 25 or even 28% may be used. While the committee is in favor of a cement grout filler, it believes that where conditions do not favor the use of the same, a bituminous filler may be used. For cement grout filler, the committee recommends a square edge brick."

Specifications for Brick Paving on Sand-Cement Mortar Bed, as adopted by the National Paving Brick Manufacturers' Assn. are, in part, as follows:

"Superfoundation. Upon that part of the foundation already prepared, there shall be added a superfoundation completing the whole, composed of 1 part of cement to 4 parts of sand, stone screenings or granulated slag, which, when thoroly rolled and compacted to a uniform density by means of a hand roller, shall be not more than 1 in in depth.

"Construction. The sand and cement for the added portion of the foundation shall be mixed in the proportions herein provided, by hand or mechanical mixer, until the mass attains a uniform shade and in such quantities that the operations of constructing the superfoundation may proceed continuously. The superfoundation shall be shaped to a true surface parallel with the surface of the finished roadway, by means of a template extending the entire width of the roadway, drawn forward upon the curbs or guide rails. When the width of the roadway precludes the use of a template spanning the entire distance the operations of shaping the superfoundation shall be performed upon sections thereof, using scantling laid upon the foundation as the guide rails. After the superfoundation has been spread and struck off a depth not less than ¼ in above the finished depth herein provided, it shall be thoroly and uniformly compacted by rolling. The roller used for this purpose shall be of the hand type, weighing not more than 10 lb per in of length. It shall be not more than 24 in in diameter, nor more than 30 in in length. Rolling shall commence at the curb and continue parallel to it at a slow pace, moving backward and forward until the opposite curb is reached. Any depressions created by rolling shall be lightly roughened by means of rakes and a sufficient quantity of aggregate mixture be added, so that when again struck off and rolled the surface shall conform to that herein provided. The operations of striking off and rolling shall be repeated until the entire superfoundation is uniformly dense and free from depressions. When the use of the template and guide rails for striking off any portion of the superfoundation is impracticable, it shall be shaped to the surface required by hand luting. All provisions for rolling, compacting and smoothing shall be observed.

"Laying the Brick. Upon the superfoundation as prepared, the brick shall be immediately laid with the better edge uppermost and the projections in one direction. Only whole brick shall be used except as provided or by special direction of the engineer."

Specifications for Brick Paving on a Green Concrete Foundation, as

adopted by the National Paving Brick Manufacturers' Assn. are, in part, as follows:

"The Subgrade, if dry, shall be lightly sprinkled with water before placing the concrete.

"Concrete for the Foundation shall be deposited, struck off and finished to the depth of ....inches as provided in the plans and specifications so that when complete, the surface shall be parallel to, and........inches below the grade of the finished roadway. The surface shall be smooth and uniformly finished, with the coarse aggregate thoroly embedded in mortar. Concrete in place shall have been so mixed, deposited, and finished, that the coarse and fine aggregate shall be uniformly distributed thruout the mass. The concrete shall be brought to the required surface smoothness and condition for laying the brick thereon by adding thereto a thin coating of sand and cement.

"The Sand and Cement for the Thin Coating shall be of a quality equal to that used in the fine aggregate in the concrete. They shall be thoroly mixed dry in advance in a mechanical batch mixer, in the proportion of 1 part cement to 3 parts of sand by volume. Mixing shall continue until the mass attains a uniform shade. Sufficient quantity shall be prepared at intervals in order that there shall be no interruption in preparing the surface of the concrete for brick laying.

"Steel Forms shall be utilized to retain the concrete and brick and serve as guide rails for the template, and when so used, shall be true to line and grade.

"Double Template. The concrete shall be brought within the requirements by means of a double template which shall consist of a 6-in steel I-beam in front and a 6-in steel channel or I-beam to the rear, held in a rigid frame with the two members parallel, spaced 2 ft from center to center, and shaped to conform to the cross-section of the roadway. The rear member shall be held in the frame with the bottom $^3/_{16}$ in higher than that of the frame member. Rollers shall be attached to the frame which shall rest, when in use, upon the guide rails.

"In Shaping the Concrete deposited from the mixer, it shall be thoroly spaded, settled and roughly surfaced immediately ahead of the double template. A sufficient amount of dry mixture for the thin coating shall be supplied continually between the framed templates so that in the forward movement, the rear template shall distribute the necessary film over the entire surface, producing the required smoothness. In cases where the use of the double-framed template is impracticable, the required surface shall be secured by templates or by hand luting.

"Note: By reason of the fact that the rear cutting edge of the double template is $^3/_{16}$ in higher than the front cutting edge, the forward movement of the template as described performs two operations simultaneously, namely: That of striking off the concrete which has been deposited upon the subgrade and spreading over its surface the $^3/_{16}$ in film of the dry mixture, which being of equal quality of the mortar in the concrete becomes an integral part of the concrete. Concrete of a consistency which will sustain the brick surface uniformly during the laying, rolling, and filling the joints is a necessary prerequisite. It is equally necessary, too, that the green concrete shall be of a consistency affording a mortar surface which will insure a perfect adhesion of the brick. The use of transverse joints in the surface or base of the roadway should not be permitted.

"Conditions Governing Laying Concrete. The use of partially hardened mortar or concrete, remixed with water, is prohibited. No concrete shall be mixed or deposited when the air temperature is below 0° C (32° F), unless during the mixing the aggregates shall be heated so that when placed, the temperature of the concrete shall be not less than 15°C (60° F). The pavement shall then be protected by sufficient covering against freezing. In no event shall concrete be deposited upon a frozen subgrade.

"Laying the Brick. Upon the foundation as prepared, the brick shall be immediately laid with the better edge uppermost and the projections in one direction. Only whole brick shall be used except as provided or by special direction of the engineer."

16. Construction Cost Data

The price of brick pavements, including foundations, varies according to local conditions, but generally will range between $1.25 and $2.50 per sq yd,

under contracts which include a fair profit to the contractor. These figures may be subdivided into items as follows:

	Minimum Cost per Sq Yd	Maximum Cost per Sq Yd
Preparation of subgrade after excavation or embankment is completed	$0.02	$0.05
Artificial foundation	0.35	
Concrete foundation, 6 in		
Materials		0.80
Mixing and placing		0.10
Sand cushion		
Materials	0.10	0.20
Placing, compacting and trimming	0.015	0.03
Brick wearing course		
Brick, hauling and piling	0.65	1.10
Laying	0.06	0.10
Rolling	0.02	0.05
Grouting	0.025	0.05
Expansion joints	0.01	0.02
	$1.25	$2.50

The necessary cleaning up of the work, sprinkling and otherwise keeping moist of the grout filler after placing, and other work incidental to the performance of the contract under such specifications as those of the National Paving Brick Manufacturers' Assn., are covered by these figures as well as interest, rental, or other charges for machinery or tools and a profit to the contractor. See (6), (7), (23), (30c) and (55).

A Formula (53) for estimating the cost of brick pavements in rural districts is as follows: Cost per square yard of foundation of 6 in of cement-concrete equals $1.90L + 0.213C + 0.138S + 0.157A + 0.040B$, where C equals the cost of cement per barrel; S equals the cost of sand per cubic yard; A equals the cost of the aggregate per cubic yard; B equals the cost of brick per thousand; and L equals the cost of labor per hour.

"Gary, Ind. (23). Contract prices for brick pavements on 6-in concrete base varied during 1914 from $2.13 to $2.18 per sq yd, while the cost data compiled from inspectors' reports show a cost to the contractor of from $1.62 to $1.72. This cost price does not include overhead expense of any kind, nor does it include the discount item referred to above. Grading is paid for as a separate item, as is all other incidental work, such as curbs, sidewalks, catch-basins, headers, etc.

Table VI.—Cost of Brick Pavement in Gary, Ind., in 1914

Improvement		Madison Ave		26th Ave		25th Ave	
Sq Yd Pavement		5289.8		8522.4		8727.1	
Labor Item	Rate in Cents	Hr	Per Sq Yd	Hr	Per Sq Yd	Hr	Per Sq Yd
Team	60	143	......	130	......	278	......
Labor	20 to 30	1746	......	1673	......	2612	......
Bricksetter	50 to 65	218	......	130	......	447	......
Foreman	35 to 40	....	......	190	......	152	......
Water boy	10 to 20	....	......	160	......	100	......
Labor cost*		....	$0.113	....	$0.086	....	$0.114
		Per M		Per M		Per M	
Brick hauled		$1.50	0.06	$2.15	0.090	$2.02	0.08
Brick cost		22.50	0.902	22.50	0.958	22.00	0.89
Cement, sq yd per bag		12.0	......	13.5	......	9.6	......
Grout-cement-water		....	0.03	....	0.026	....	0.036
Total unit cost			$1.105		$1.16		$1.12

*Includes cost of making sand cushion, laying, rolling and grouting brick."

Method of Figuring Cost of Brick Paving on a Green Concrete Foundation (26). "This is a method of arriving at a COST only. The figures used may not apply at all to any case in hand, but in arriving at what the cost of a brick road is in any particular case the actual cost of the several items must be ascertained. Then the real cost can be determined by following the method outlined."

Assumed prices for illustration: Cement at $1.40 per bbl delivered. 4 in brick at $14 per M, f. o. b. factory. Sand at $1 per ton delivered, at 3000 lb per cu yd. Broken stone, $1.25 per ton delivered, at 2600 lb per cu yd. Haul for brick, 1½ miles at 30 cents per ton-mile.

Assumed proportions: Base, 4 in, 1 : 3 : 6 concrete, requiring per cu yd 1 bbl cement, 0.45 cu yd sand and 0.95 cu yd stone.

Cost of Concrete Base:	Per Cu Yd	Per Sq Yd
Cement	$1.400	
Sand $3000 \times \frac{0.45}{2000} \times \$1.00 =$	0.675	
Stone $2600 \times \frac{0.95}{2000} \times \$1.25 =$	1.544	
Water	0.100	
Mixing, placing and finishing	0.650	
	9)$4.369(	$0.485

Cost of Brick:	Per Ton	Per Sq Yd	
Brick f. o. b. factory at $14.00 per M	$2.80	$0.560	
Freight	0.60	0.120	
Hauling, 1½ mile at 30 cents	0.45	0.090	
Laying and rolling		0.080	
			$0.850

Cost of Grouting:

Cement grout filler, 1 bbl cement + 1 bbl sand grouts, 25 sq yd, 4 in brick.

	25 Sq Yd		
1 bbl cement	$1.400		
1 bbl sand	0.222		
	25)$1.622(	$0.065	
Mixing and applying:		0.040	
			0.105
Covering and Curing:			0.005
Total			$1.445

17. Special Forms of Brick Paving

Hillside Brick. The special form known as hillside brick has recently come on the market in response to a demand for reduced slipperiness in brick pavements on grades. The hillside brick is the ordinary paving brick with one of the longest edges in the face exposed to traffic chamfered off or with grooves in its wearing face.

The Chamfered Brick are laid as usual except that care is taken to have this chamfered edge always placed down grade, and next to the square edge of the brick adjacent. After the joints have been filled with cement grout in the ordinary manner, the joint filler, just before it is set hard, is removed from the chamfered space by means of stiff brooms, and a fairly deep groove is thus left across the pavement on the up-hill side of each course. The ridged or corrugated pavement thus presented to the traffic is less slippery than the ordinary smooth pavement with completely filled cement joints.

Table VII.—Character and Cost of Brick Pavements Laid in 1916 in Several Cities

From *Municipal Engineering*, March, 1917

	Sq Yd	Base: Thickness in In	Base: Proportions	Cushion: Thickness in In	Cushion: Kind	Thickness of Brick in In			Cost per Sq Yd Pavement and Foundation
Joliet, Ill.	23 250	5	....	1¼	Sand	4			$1 90
Rockford, Ill.	68 987	5	1 : 3 : 6	1½	Sand	4			1 84
Springfield, Ill.	17 027	5	1 : 6	1	Sand	4			1 73
Ft. Wayne, Ind.	21 005	6	1 : 3 : 6	2	Sand	.			1 79
Clinton, Iowa	22 608	6	1 : 3 : 6	1¼	Sand	..			2 20
Topeka, Kan.	46 000	6	1 : 2½ : 5	1½	Sand	3			1.77
Louisville, Ky.	59 758	6	1 : 3 : 6	1½	Sand	4			1 61
Baltimore, Md	7 616	6	1 : 3 : 6	1	Mortar	4			2 22
Grand Rapids, Mich.	34 512	5	1 : 3½ : 7	1½	Sand	..			1.90
Kalamazoo, Mich.	26 860	6	1 : 8	1½	Sand	.			1.74
Minneapolis, Minn.	22 395	5	1 : 3½ : 7½	1	Sand	4			2.30
St. Louis, Mo.	262 600	6	1 : 3 . 6		1 : 4 Mor	4			1.85
Jamestown, N. Y.	19 947	5	1 : 6	1⅓	Sand	.			2.08
Poughkeepsie, N. Y.	25 000	5	1 : 3 : 6	1	Mortar	3½	1 : 1 Grout	Asphalt	2.16
Circleville, Ohio	10 952	6	1 : 2 : 4	2	Sand	..	Tar Mastic	......	1 78
Cleveland Ohio	254 996	6	1 : 3 : 6	1	Mortar	4	1 : 1 Grout	......	2.25
Portland, Ore.	10 730	6	1 : 3 : 6	1	1 : 4 Mor	.	1 : 1 Grout	......	2.33
Greenville, S. C.	19 000	4	1 : 3 : 6	1¼	Sand	4	Tar	......	1.99
San Antonio, Tex.	41 571	5	1 : 3 : 6	1¼	Sand	3	Asphalt	.....	2 60
Seattle, Wash.	112 581	5	1 : 3 : 6	.	Mortar	.	1 : 1½ Grout	......	2 55
Racine, Wis.	39 326	5	1 : 3 : 5	2	Sand	4	Grout	Sarco	2 15

Grooved Brick. A novel type of hillside brick was laid in Toronto in 1914. It is described (22a) as "combining the distinctive features of the ordinary wire-cut-lug brick with two transverse grooves, about 3 in apart, on the wearing surface, designed to give horses a foothold on steep grades. The bricks are laid longitudinally with the street. Joints are broken on each brick so that instead of extending in lines across the entire width of the street, as in the case with ordinary hillside brick, each groove is no longer than the width of the brick. This affords shoe-calks opportunity to get a grip almost anywhere. However, as the grooves are broken at short intervals, broad tires bridge them on alternate courses of brick and roll over the pavement without experiencing an appreciable jolt.

"None of the hillside brick was laid in courses at right angles to the curb, but they were laid obliquely across the street, a method necessitated by laying the brick longitudinally in the direction of the length of the street. The pavement has a 6-in concrete foundation and a 1½-in sand bed, with cement-grout filler mixed 1 to 1. Grouting was begun at the foot of the grade, as otherwise the thin grout would have flowed down the longitudinal joints and overflowed the lower part of the pavement. Small quantities of grout by the shovelful were poured at a time, and the surplus was quickly brushed forward up the grade. The final course of grout was squeegeed until the surface of the joints was full, flush with the pavement, care being taken to keep the joints full until t e setting began. After the final course of filler began to set, the transverse grooves in the brick were brushed out with wire brooms. The brushing was not really necessary, as the grout in the grooves wears out under the impact of horses' shoe-calks, but the process made the grooves serviceable at once." See also (31b).

Nose Brick are brick of a special form for fitting against the heads of street-car rails. They are like ordinary paving brick except that at one end the corner of the upper side is rounded off into an ogee curve, so as to permit the end of the brick to go up against the web of the rail and the surface of the brick to be close to the head of the rail near the top, thus enabling a tighter joint to be made between the paving and the rail. This result is similarly attained by the use of special filler brick, made with chamfered edges, of the proper thickness to permit the brick to be placed in the area between the web of the rail and the plane of the outside of the head, so that the ordinary brick may then abut against the head of the rail and the outside face of the filler brick. On the inside of the T-rail, where a flange-way must be provided for the street-car wheels, filler brick are provided for occupying the area between the web and the plane on the inside of the head of the rail, and then a special form of brick similar to hillside brick, and having one chamfered edge, are laid lengthwise as runners next to the filler brick. A channel for the street-car flanges is thus provided, the inner side of which is sloping instead of vertical, enabling narrow tired vehicles to avoid being held by this channel. The proper construction of a brick pavement in connection with street-car tracks is an extremely important and difficult matter. The area of greatest weakness in brick pavements is usually a narrow one along the street-car rails, and this weakness appears to be occasioned by the usual difference in rigidity between the street-railway construction and that of the brick pavement, together with a usual lack of precaution against the entrance of water at this point to the interior of the pavement construction, or the difficulty of maintaining the proper degree of imperviousness in the pavement within this area. Any entrance of water along the rail will sooner or later affect the position of the sand cushion under the pavement or even the foundations and then the pavement itself. The filling of the irregular area between the web of the rail and the vertical planes passing thru the outsides of the head of the rail is a most difficult matter, and various expedients have been tried.

Filling this area with mortar or concrete is usually most difficult if not impracticable. The filler brick above mentioned seem to be an improvement, but their rigidity, and that of the mortar used with them, frequently results in the cracking of this filler where the rail is not sufficiently rigid under the loads coming on it, and such cracking permits the entrance of moisture or the escape of the sand cushion. In Baltimore, it has been the practice to use wooden plank of the proper thickness to fill these spaces, but it is difficult to secure tight joints in the plank around the fish plates, tie rods, bonds, etc. The usual concentration of the effects of traffic, on the strip of the pavement immediately adjacent to the rail, demands the greatest possible precautions and the best possible work on this portion of the pavement if uniformity of the pavement surface is to be had in service. See Sect. 23. Vitrified brick or other blocks are frequently used in one or two lines as runners along the rails of street-car tracks where a bituminous pavement is used for the balance of the roadway, because of the difficulties of constructing and maintaining a proper continuity in the bituminous pavement if brought against the head of the rail. Where the car track construction is of a high character, the use of brick or similar smooth blocks gives satisfaction, but if the car track construction is what might be called flimsy and unsubstantial or lacks rigidity under the vehicles using it, the relatively small mass of the brick does not seem to be sufficient to permit it to give the satisfactory results desired. In such cases, the brick even become displaced, the joints open and water is permitted to enter the pavement at this joint. This results in more rapid deterioration of the roadway surface as a whole. In such cases of inferior construction of car tracks in the pavement, the use of brick or similar small smooth blocks should be avoided, and larger blocks, such as stone paving blocks, should be used instead, in order to secure the utmost advantage to be had from their greater inertia and ability to resist displacement.

Bituminized Brick were laid on Stark Street, Portland, Oregon, in 1893. The brick had been boiled in coal tar before being laid, and this section of pavement remained in service for 17 years. In 1906, nose brick, which had been boiled in asphalt, were laid along the street-railway tracks in Los Angeles, and in 1912, a small area, at the corner of Second and Market Streets, San Francisco, was laid with similar material. Adjoining this latter area, sections of basalt block and sheet-asphalt were laid. It is claimed that the treated brick showed less wear after 2 years' use than either of the other sections. Similar pavements of brick soaked or boiled in bituminous material, have been laid in Nashville and Chattanooga, Tenn. The treatment of the brick in the above cases was more or less crude and caused the bituminous material to penetrate only from ½ to ¾ in below the surface. The recently developed treatment causes a much more thoro impregnation of the brick and saturates the brick with from 6% to 15% of its weight with bitumen. The treatment seems to increase the imperviousness of the brick, improve the adhesion of any bituminous filler used in the joints, reduce the noisiness and slipperiness of the pavement, and increase the sanitariness of the pavement. More important, however, than any of these facts is apparently the effect on the wearing qualities of the brick. A remarkable reduction in the loss under the rattler test is apparently secured. Perhaps the most noticeable result is the tremendous increase in uniformity of loss among the individual brick when they have been properly bituminized. Table VIII shows the results of some tests made by R. W. Hunt & Co., on brick both treated and untreated. In

Table VIII.—Comparative Tests of Shale and Clay Brick, Treated and Untreated with Bituminous Material

Brick	Made From	Weight Before Test in Lb		Weight After Test in Lb		Percent Loss in Weight	
		Before Treatment	After Treatment	Before Treatment	After Treatment	Before Treatment	After Treatment
Sterling Brick Co.	Shale	50.66	56.75	23.64	48.37	58.34	14.77
Terre Haute.........	Shale	46.50	48.97	17.69	42.75	61.96	12.70
Mack Manufacturing Co.	Fire Clay and Shale	45.25	47.49	31.32	40.98	30.79	13.71
Corning Block........	Shale	48.65	51.33	36.77	44.50	24.42	13.31
Jamestown Shale Paving Co.	Shale	49.75	54.60	30.18	47.24	39.34	13.48
Hocking Valley Brick Co.	Shale	47.95	49.94	34.32	43.48	28.43	12.94
Metropolitan Block....	Shale	50.03	54.53	38.25	48.28	23.55	11.46

Note: In each case ten bricks were used, 5 treated and 5 untreated. Weight of abrasive material as follows: Small shot, 225 lb; large shot, 75 lb. Number of revolutions, 1800 at rate of 30 rev per min. Each brick weighed separately before and after test.

each case, bricks of the same quality and from the same batch were used in the comparative tests and were in all cases seconds. It will be seen that while the rattler loss of the untreated brick runs from 23 to over 60%, that of the treated brick runs between 11.4 and 14.8%. The uniformity of the brick under wear (see Art. 8) seems therefore tremendously increased. Further, the tests apparently show that a brick which has not been burned to the ordinary degree of vitrification can be made, by this treatment, to give an abrasion loss lower than ordinarily specified for the best grade of vitrified brick. Apparently the impregnating bitumen by its adhesiveness prevents the brick from losing particles which would break off the untreated brick, and thus perhaps cushions the cell walls of the brick so as to greatly increase their resistance against breaking down under shock. From the manufacturers' point of view, the treatment will apparently enable the burning of the brick to be stopped at a considerably lower point than is now necessary for the No. 1 pavers, and further enable the disposing of practically all of each burning as No. 1 pavers, instead of only from 60 to 70% as is usually the case. Apparently a great improvement of even the best vitrified brick pavement is offered by bituminizing brick. If, after more thoro trial, the pavement shall fulfill the promise held out by the experience to date, a wider field will be opened for such pavement and many of the now existing objections to vitrified brick pavements will be removed.

The Manufacture of Bituminized Brick is described as follows: The burning as ordinarily conducted is stopped 2 or 3 days sooner than for vitrified pavers. The brick are then cooled down to a handling temperature and run into a tight cylinder. A vacuum of 25 in is produced in the cylinder while the brick are at a temperature of approximately 177° C (350° F). The bituminous material, in the meantime having been heated in a tank, is now discharged into the cylinder, filling it to a point above the brick, where a pressure of approximately 160 lb per sq in is produced and maintained from 1 to 3 hr. The cylinder is then drained, all surplus bituminous material being returned to the tank. The brick are then transferred to an annealing chamber and allowed to cool. It is claimed that the process produces a uniform impregnation.

Vitrified Cubes. In the effort to reduce the first cost of vitrified brick pavements, J. Y. McClintock, County Engineer of Monroe County, N. Y., in 1908 began experimenting in the use of artificial cubes made from local clays and shales in the same manner as the ordinary vitrified paving brick. These cubes were 2 or 2½ in each way, and were laid on various kinds of foundations with a sand cushion under the cubes. Experiments with cubes of other materials were made contemporaneously. The vitrified clay and shale cubes in these experiments have been remarkably successful under the local traffic conditions. The joint filler used was in some cases sand or sandy loam; in some, cement grout; and in other cases, bituminous cement was used. The cubes were laid in different ways, in some cases, individually by hand; in some cases, from pallets containing from 124 to 144 cubes each; and in other cases, they were simply loosely spread and raked into place. It was found that too great a variation in the depth of the sand cushion was as undesirable as in the case of vitrified brick. Too wide joints permitted the removal of a sandy filler by fast moving automobile traffic, resulting in excessive spalling and wear along the joint lines. In the latter case, improvement was had by the use of a bituminous material over the pavement after the surface had been cleaned off and the sandy material in the joints removed to a moderate, but uniform, depth below the surface of the cubes. It was further found that the edge of the cube pavement could be successfully held by a macadam shoulder, thus enabling a gradual transition from the hard surface of the road to the earth shoulder outside, and the prevention of ruts along the edges of the harder pavement. The cube pavement seems to be sufficiently flexible under frost action to make it well suited for a surfacing with a macadam base, and to give a surface that is very satisfactory in both wet and dry weather for traffic. Furthermore, as it can be laid early and late in the working season and easily patched, it seems to have important advantages. The resistance to wear of these vitrified cube pavements has been admirable, and when laid on a concrete foundation and with grouted joints, they have worn very well under heavy motor traffic and medium team traffic. When laid on a macadam base with fairly wide sand joints, they stand well under moderate traffic. When so laid with a sand filler and superficially coated with bituminous material, they have stood considerably heavier traffic. The indications are that a well burned vitrified shale cube laid on a concrete foundation with cement grouted joints will stand satisfactorily the traffic on all but a few of the most heavily travelled country roads.

The cost of the first vitrified cube pavements on an old macadam base was reported in 1909 as $1.17 per sq yd. The cost at the plant was $3.20 per thousand for the cubes, or 71 cents per sq yd, while it is estimated that it would be possible to reduce this cost 50% by more efficient methods in burning and handling the cubes. In 1913, an actual reduction in the cost of the cubes to $2.50 per thousand or 55 cents per sq yd, was accomplished. The freight on the cubes from the plant was 11 cents per sq yd, or the cost delivered was 66 cents per sq yd, as against 85 to 90 cents per sq yd for ordinary paving brick. See (37).

MAINTENANCE

18. Methods of Maintenance

The maintenance of a properly built brick pavement should be so slight as hardly to justify extended discussion of the subject. By maintenance is to be understood no consideration of the cleaning of the surface. This

cleaning, while as important in the case of brick pavements as in any others, is a separate subject and fully discussed under its proper head (see Sect. 22). The maintenance proper of a brick pavement will consist of restoring the uniformity of its surface or correcting defects resulting from faults in the construction. From one cause or another, an individual brick in the surface may prove to be or become defective and immediately defects in the surrounding area appear and grow rapidly. The removal of the defective brick or bricks and their replacement by suitable bricks with a concentrated view to securing the greatest possible homogeneity and uniformity of the entire surface should be had as promptly as possible.

The Expansion Joints may need some attention in order that the elastic material in them shall remain everywhere even with and protecting the edges of the bricks adjoining the joint. Also, in case cracks appear in the pavement, these opportunities for water to reach the interior, with probable resultant damage, should be promptly and finally closed by filling them with melted bituminous cement of proper character.

The Wearing Down of the Surface of a well built vitrified brick pavement is such a slow matter that its end of life on this line is beyond contemplation. The disintegration of individual bricks in the pavement is another matter and not by any means infrequent. The deterioration of considerable areas with a resulting damage, even to the point of a just condemnation of the whole pavement, is rapid if neglect is accorded the first symptoms of such a process taking place.

Bituminous-Filled Brick Pavements have sometimes given excellent service with slight maintenance expenditures for many years until they have become objectionable, under the local conditions, for the reason of their then excessive noisiness due to the badly worn-off upper edges of the brick. Some such pavements have then been taken up and the same brick relaid bottom up with satisfactory results. This might be considered Maintenance. It would be impracticable in cases where cement grout has been originally used for the joint filler.

Replacing Brick Paving After Refilling Excavations (45). "In making the cut thru the pavement, alternate bricks will sometimes be broken in the middle, leaving a series of broken bricks along the edge of the cut. These half bricks must be toothed out with a chisel so that none but whole bricks remain. It is then possible to break joints in patching. A patch which does not dove-tail into the original pavement, but leaves a long straight longitudinal joint between patch and pavement, cannot be too strongly condemned. A long handled 18-in chisel is the best instrument to use in making the original cut in a pavement. After an opening has been broken with a maul, the chisel can be used to cut and pry out each brick separately, making a cleaner opening and facilitating the patcher's job. Matching brick for the patch is an important matter. If the color and size coincide with the original pavement, the patch will be scarcely noticeable. The brick should be carefully measured in matching for size. Where the new brick are a hairbreadth thicker than the old ones, the courses are thrown out of series and good joints are impossible."

Removing and Cleaning Brick by Compressed Air Power (25). "The equipment used for this work consisted of a 15-HP Sullivan Class W-K-3, portable, single stage air compressor, the compressor being operated by a gasoline engine, mounted on the same truck with the compressor and operating the compressor thru a gear and pinion. This outfit furnished compressed air for a Sullivan DA-15, 25 lb plug drill, and a Sullivan DB-13 hand bushing tool equipped with bits like that on a cold chisel. The larger of the two tools is used for tearing up the brick, and the smaller for cleaning the old mortar and grout from them. With the plug drill one man can remove 4 sq ft of pavement in 15 or 20 min, taking the bricks up either one brick at a time or several, as desired. When doing this work by hand, the workmen were frequently obliged to break several bricks which were perfectly good, in order to get out one,

so that the loss was considerable. Before the purchase of this outfit the cost of removing and cleaning bricks by hand was $24 per M and a crew of 10 men was able to handle 1000 bricks per day. The detailed cost of operating the compressor and drill outfit was as follows:

1 Compressor engineer	$3.00
7 Gal of gas at 18 cents	1.26
4 Operators at $1.85	7.40
Lubricating oil	0.25
Total cost per day	$11.91

"The above does not include interest or depreciation. Crowley estimates that about 2000 bricks are removed and cleaned in 8 hr with the two tools. This brings the cost of taking up and cleaning to $5.96 per M bricks. On work done with this outfit in 1914 a crew of 40 men was cut down to 18 men. It is estimated that this outfit pays for itself on every 100 000 bricks taken up and cleaned. Savings included labor on the brick, saving in the sand cushion, saving in time in making the bed under the brick and in laying the brick. Cement and grouting are also saved."

19. Bituminous Carpets

The effort has been made to reduce the noise and slipperiness of some brick pavements as well as to lengthen their life under traffic by applying to their surfaces a carpet composed of bituminous cement and sand or gravel. Some of these experiments have been fairly successful while others have been quite the opposite. The obstacles to success seem to be mainly those of securing proper adhesion of the carpet to the brick surface and of securing such a proper body to, or cohesion in, the carpet itself, as will enable it to resist successfully the tendencies of the traffic to strip the carpet from the pavement or to disintegrate it. If the carpet is to be successful, it must be able to resist to the last the tendency to peel off the brick surface, and it must have sufficient body to resist the disintegrating effect of the traffic which tends to push it into waves, or to crumble it into a loose mass. It is evident from the experiments that have been made that there is a limit to the amount of traffic which any such carpet can successfully withstand, and the attempt to provide a bituminous carpet on a brick pavement, should not be made where the severity of the traffic is greater than a certain degree. At the present time, it is impossible to express this limited degree of severity of traffic in formulas or figures. Aside from the adhesive and cohesive qualities of the bituminous cement itself, the composition of the carpet and its thickness have much to do with its resistance to disintegration under traffic. For instance, considering that a sheet-asphalt pavement is a carpet, there is no reason why it could not be laid on a brick pavement as a foundation, and its ability to withstand traffic when so laid would be equal to the ordinary ability in this direction of any sheet-asphalt pavement properly proportioned and properly laid. On the other hand, it is evident that a very thin carpet composed of the same asphaltic cement and sand would be least resistant under the same traffic. Between these two extremes may be expected to be found various mixtures and thicknesses suitable for different degrees of traffic. The adherence of carpets to brick pavements seems to be more satisfactory in cases where they are placed on pavements with bituminous joints than in those cases where a cement filler has been used in the joints. It would probably be greatest on bituminized brick (see Art. 17). See (28).

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SECTION 21

CEMENT-CONCRETE PAVEMENTS

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GENERAL DATA

1. Historical Development

In 1879 North (51) stated that "In Scotland a concrete has been used with Portland cement, for binding. The surface was very good, but when the road commenced to break, it went to pieces very fast."

The First Portland Cement-Concrete Pavements in the United States are usually referred to as being laid in Bellefontaine, Ohio, in 1894, but as a matter of fact, the year before, J. Y. McClintock, County Engineer of Monroe County, N. Y., put down on South Fitzhugh St., Rochester, a section of Portland cement grouted macadam. This was a forerunner of the modern concrete pavement of the Hassam type. An excerpt from McClintock's 1894 Report (55) is as follows:

"There are many miles of streets where a cheap pavement is requisite and where macadam with trap rock would be suitable except that it seems desirable to get rid

of the small amount of mud which is usually present, and to have a surface that can be washed off clean. To meet this requirement we tried in 1893 the following on South Fitzhugh St. north of the canal. The surface of an existing macadam pavement was picked off and a layer of trap rock 6 in thick in the middle and 2 in thick at edge of paved gutters was put on and thoroly rolled with a steam roller. After this was done, instead of putting on a binding material and rolling that in as usual, Portland cement grout, one of sand to one of cement, mixed to the consistency of cream was carefully poured in so as to fill all the voids between the broken stone and form a solid matrix to hold each stone firmly in position. The stone was thoroly wet just before pouring in the grout. One barrel of cement was used to each 8.7 sq yd of pavement. After the mortar had set for 24 hr, sand was thrown over the surface and water was sprinkled upon it and all travel was kept off it for 9 days. This has been down 8 months and already shows that the size of stone used was too small; it would all pass thru a 1½ in ring. The stones are so small that the calk of a horse shoe throws a stone out bodily sometimes. It will be well to try this again with stones which will pass a 3 in ring and will not pass a 2 in ring. The cost of this pavement was $1 per sq yd."

McClintock in March, 1913, testified concerning this work, in the case of the Hassam Paving Co. versus the Consolidated Contract Co., as follows: "The piece of pavement laid developed irregular temperature cracks and on one portion of it where the hacks stood in the shade of the court house, the horses would drill holes with their feet in kicking off flies, so that it soon became a question of how the pavement could be maintained. (After eight months' use, the horses' calks were picking out some of the individual stones.) It was some 2½ years after the pavement was laid, . . . that it was deemed wise by the city authorities to cover the new portion of the roadway with asphalt.

The Bellefontaine Pavements were of the two course mixed type. From 1894 until 1909, the construction of concrete pavements of either type made little headway, one reason probably being the high first cost of such pavements under the then existing conditions, and another being the especial difficulty of making minor repairs to them.

Wayne County, Mich., began in 1909 the construction of a considerable mileage of concrete pavements. While this work was at first largely of an experimental nature, it was intelligently done, and the wide advertisement of the success of the results induced further experiments in many localities.

Table 1.—Summary of Square Yards of Concrete Pavements on Roads, Streets, and Alleys Constructed to December 1, 1916 (53b)

	Prior to 1909	1909	1910	1911	1912
Roads.........	34 061	32 626	151 148	291 077	1 869 486
Streets........	444 864	325 158	682 637	1 011 440	3 326 029
Alleys.........	112 491	86 825	107 874	136 674	185 703
Totals.......	591 416	444 609	941 659	1 439 191	5 381 218

	1913	1914	1915	To Dec. 1, 1916	Totals
Roads.........	3 339 185	10 608 421	12 050 909	16 533 129	44 910 042
Streets........	8 946 219	4 830 604	5 933 879	7 501 739	28 002 569
Alleys.........	308 365	300 138	612 921	894 280	2 745 271
Totals.......	7 593 769	15 739 163	18 597 709	24 929 148	75 657 882

2. Characteristics

For the sake of making clear the statements to follow, let it be assumed primarily that a cement-concrete pavement is one in which the artificial surfacing for the roadway is built of a concrete composed of hydraulic cement, sand, and gravel or broken stone, all of predetermined proportions, and is not covered, or protected from wear, by a carpet or coating of appreciable thickness of bituminous cement and other material. Then all those roadways, of which a cement-concrete layer is covered by a carpet of bituminous material, will naturally fall together into another class where a concrete base or foundation supports a wearing surface composed of block paving, sheet or rock asphalt, bituminous carpets, etc, and in the consideration of these instances of the use of concrete, the latter will be referred to as the concrete foundation.

The use of concrete for both roadway surfaces and foundations is not new. In 1893 the concrete pavement was discovered, tried out and abandoned. It was found to possess certain inherent defects and, under the then existing conditions, these proved so serious that its economical use was found to be limited so as to result in the practical abandonment of this form of surfacing for the time being. With the changed conditions now existing, the use of concrete for roadways has again begun. The increase of traffic has demanded stronger roads. The reduced ratio of horse-drawn to total traffic has changed the average character of the stresses on the surfacing material. The immense reduction in the cost of hydraulic cement and the improvements in machinery for mixing and placing the concrete have aided the latter to compete with other road crusts in first cost and also in long-run cost. It seems that under the changed conditions there are at present many cases where existing circumstances, such, for instance, as poor natural foundation for, and heavy traffic on the road, or convenience in the supply of materials for concrete, justify or even demand its selection for at least a part of the road crust. On the other hand, the tendency of certain road authorities and others to rush to concrete as a panacea for all road ills is to be deplored as both irrational and extravagant. In these days the great problem for road authorities is the proper selection of the form of construction best suited for the circumstances of any particular case, and a sufficient variety of surfacings, including concrete, is now available to permit true economy to be had by a proper choice.

Of the factors influencing the decision for or against the selection of concrete as the road surfacing may be considered first cost, long-run cost, durability, ease of maintenance, cleanliness, resistance to traction, slipperiness, sanitariness, acceptability, and favorableness to travel.

Cost. Only too frequently, this consideration is limited to first cost and fails to include, as it should, the interest charges on first cost and the cost of maintaining the pavement in as good condition as when first completed, or a depreciation charge, in order that a fair comparison may be drawn. See (15). Concrete can never be as low in first-cost as macadam under the same conditions, because of the introduction into the former of cement for which an additional cost has to be met. Ordinarily competition may be had, often successfully, by a proper assumption that a less thickness of concrete will be as strong as the macadam to be prescribed, and further, that it is frequently possible to use in the concrete a local material for the aggregate which may be secured at a smaller cost, than necessary for a proper stone for the macadam. A local granite may make an excellent

concrete, when it would prove entirely unsatisfactory, because of its lack of binding qualities, for macadam, and, if macadam were to be built, the cost of importing a suitable stone might offset the additional cost of making concrete from the local granite. In the same way, where small sandy gravel is plentiful in a locality and good stone for broken stone macadam is required to be imported at a considerable expense, frequently gravel concrete roads or gravel concrete foundations, carrying a bituminous surface, will be found to be the economical solution. Contrary to the arguments of many of the advocates of concrete pavements, a concrete surfacing is not permanent in the sense that it will last indefinitely without repair. Concrete roadways, in addition to the interest charges to be figured in their long run cost, require continuous expense for maintenance and repair. Except possibly in those cases where a curb adjoins the edges of the concrete roadway, the shoulders, even if the concrete itself does not, begin the day after the completion of the roadway to need maintenance. While the shoulder maintenance may not be a part of the maintenance charges for the concrete itself, it certainly is a part of the road maintenance especially where, in order to keep the first cost down, the concrete surface has been built too narrow in width to carry on it all the traffic and a considerable portion of the latter constantly turns out on the shoulders. The concrete surfacing itself will, after a period dependent of course on local conditions, require repairs and it is an inherent difficulty of concrete, that repairs to it are not easily made. This fact was one of the main reasons for the abandonment of the earlier efforts to use concrete for roadway surfaces. While these repairs may seem in some respects relatively slight, the expense for them will be inversely large. Reliable figures of cost for maintenance of concrete roadways are not as yet at hand but the foregoing may serve to indicate, from the point of view of cost, the factors to be considered in this connection and the points of weakness in some of the arguments that have been advanced for the more general adoption of concrete roadway surfaces.

Durability. Reference has been made to the fact that concrete is not easy to repair. The frequency of repair may depend largely on local conditions, but it is also affected by certain peculiarities of any concrete. The mixing together of four different materials and the placing of the resulting mass in the roadway give many opportunities for irregularities to occur. A most desirable feature of any road surface is an ability to wear uniformly and this is frequently, if not generally, more desirable than a less uniform, even if slower, rate of wear. The difficulties in the way of the necessarily high degree of uniformity in cement-concrete for roadway surfaces are apparent, when it is recognized that few sources of broken stone deliver a uniform product; that there is frequently considerable variation in the ledge or quarry itself; that there often is variation even between the products of different days from the crusher and screens; and that segregation of the smaller from the larger sizes generally occurs in loading, shipping and handling this product. The same may be said as regards the sand in many cases. The quantity of water present in the mixture is frequently more or less irregular, and segregation and other causes for non-uniformity generally arise during the mixing and placing of the concrete. All these contribute to the presence so generally noted in concrete roadway surfaces of spots of unequal abilities to resist wear and to the consequently resulting holes so difficult of proper repair, which form one of the main objections to this type of pavement. While proper supervision does reduce to some extent the lack of homegeneity in results, certain inherent irregularities can be

only reduced by improved mechanical means while certain others seem inevitable. For instance, the natural irregularity in position of the stone in the surface of the placed concrete may be reduced to a considerable extent by rolling so that, just as in good broken-stone macadam, the majority of the larger pieces of stone in the surface will lie with a face exposed to subsequent wear instead of an edge as is found in most cases of insufficiently rolled macadam. Harrowing a layer of broken stone will result in greater uniformity as to size of the pieces of stone in the surface. Hence there seems to be good ground for some of the claims of the advocates of a concrete roadway surface formed by grouting the broken stone spread and rolled in place such as in the Hassam pavement. Further the physical bond thus secured between the stone particles is worth considering as an additional factor for strength and durability.

Difficulties of Repairing. Concrete is not easily repaired so as to be satisfactory. The difficulty of remedying a slight depression worn into the surface under traffic generally leads to letting such a defect increase to material dimensions before attempting its repair, which delay is of course objectionable. To repair any depression with any degree of satisfaction it has been found necessary that the depth of the hole be, or be made, sufficient to provide space for placing in it aggregate of the same size as that which forms the adjoining surfaces and flush with them. Also it is necessary that the new concrete be of uniform thickness, not tapering off at the edges. This means, that for the proper repair of a hole, the old concrete must be more or less cut away. Even then if a good bond is not secured between the new and the old concrete, the joints in the surface soon become objectionable. When the ordinary concrete roadway surface begins to need repair, it is practically only a question of a short time when the concrete surfacing will have to be abandoned as such, and turned into a concrete foundation because of the difficulties of repairing the concrete so as to leave it satisfactory as a road surface. If a concrete roadway is built with gravel, notwithstanding that the average greater strength of gravel concrete is greater than with broken stone concrete, the lack of mechanical bond obtainable from the rounded stones in the surface renders the latter particularly susceptible to damage by the shod feet of draught animals. The blow of a horseshoe may break the cementing mortar around a stone and the pushing or twisting of the foot may then easily dislodge the rounded stone from its place. Of course the adjoining stones are then more easily dislodged and the hole in the surface grows rapidly and needs repair. The difficulties of proper repair are so well recognized that many engineers are now recommending such work to be done with bituminous concrete instead of cement-concrete, but of course this is only a step toward the ultimate transformation of the concrete roadway into a concrete foundation.

Cracks and Joints. Again it seems pretty generally agreed that concrete roadways are liable to objectionable cracking under the influence of changes in temperature and in the conditions regarding moisture present. After being placed, the wet concrete shrinks considerably in setting and drying and this change of volume produces cracks in the surface. These cracks form points of weakness and foci of deterioration more or less serious according to their distribution and concentration. The effort is usually made to concentrate them in regularly occurring joints and these joints are often predeterminedly built in place with cumbersome iron or steel plates, which themselves are objectionable to traffic. These expansion joints increase in obnoxiousness as the road gets older and wears down, and ulti-

mately, in order to relieve this feature, if for no other reason, the coating of the whole road with a bituminous or other surface or pavement is necessary. If these expansion joints are not provided in the first place, the concrete roadway surface may develop cracks irregularly under alternate wetness and dryness or heat and cold, and these cracks break away on their edges and ultimately develop into objectionable places in the surface. Apparently the only remedy is to cover the entire surface with a carpet or pavement. The concrete roadway then becomes a concrete foundation, and if it can be foreseen, that such an end is probably to result within a limited time, reasons of economy demand its careful consideration before reaching a decision to attempt the concrete roadway construction in the first place.

Ease of Maintenance. Special machinery is not required for maintaining concrete roadways and in this respect they may have an advantage over such pavements as bituminous concrete and sheet-asphalt. Heaters, mixers, and unusual tools are not required nor even steam rollers for any but the largest repair jobs.

Cleanliness. Concrete pavements are fairly easily kept reasonably clean. They are perhaps less susceptible of dustlessness and thoro cleanliness, than is an asphalt surface or the best brick pavement, but on the other hand they are more so than macadam or even a good stone block pavement.

Resistance to Traction. This is extraordinarily low in the cases of concrete pavements, and few pavements lead them on this point.

Slipperiness. Concrete pavements are generally more slippery than macadam and stone block pavements, except perhaps in some cases of the latter where the joints are filled with cement mortar, but less so than wood block, bituminous pavements generally, and well laid brick pavements.

Sanitariness. Concrete pavements are slightly less sanitary than bituminous surfaces and pavements; are equal in this respect to the best laid brick; and are more sanitary than stone block pavements or macadam.

Acceptability. That is, the bases of personal or local preferences and of aesthetic consideration and of noiselessness. The glaring effect of the mortar in the concrete is frequently objectionable even when dark colored stone is used for the aggregate. On the the other hand, a light color of the concrete may be beneficial for unlighted roads thru woods especially where there is much travel at night. As to noiselessness, concrete pavements offer slight objections on this count. They are productive of more noise than bituminous surfaces and pavements or macadam, but of less than brick or stone blocks.

Favorableness to Travel. Concrete pavements are somewhat less favorable to travel than macadam or bituminous surfaces and pavements, and more favorable than stone blocks or brick in that their surface rigidity lies between the two types mentioned. An extremely rigid inelastic surface is objectionable to passengers traveling over it even when the vehicular devices for lessening the inevitable shocks are of the highest efficiency. Animals naturally prefer the softer materials on which to tread especially when unaccustomed to metalled or paved roads. As the proportion of surfaced to unsurfaced roads increases the latter objection to concrete will be somewhat reduced. Complaints from motorists using newly completed stretches of concrete roadways are that an unpleasant vibration was noticeable to the passengers in going over such roads, and it seems probable from the descriptions, that such vibration was due to minor unevennesses or corrugations in the surface unnoticeable to the eyes or at low speeds. If the speed is high enough, this vibration can be de-

tected on the best concrete roadways tho it seems imperceptible on macadam or on good bituminous surfaces and pavements. Those who lean toward concrete roadways may attempt to meet the objections by suggesting that the removal of nearly all grounds for objection and a considerable strengthening of the arguments for the more general use of concrete for roadways may be had by providing a bituminous surface on the concrete.

Concrete Pavements vs Concrete Foundations. Because of the difficulties, inherent with cement-concrete and incidental to its construction, of securing uniformity and homogeneity in the wearing surface of the concrete roadway; because of the initial extra cost for the proper results in many cases; because of its peculiarities, often offensive, such as high rigidity, dustiness, glaring color when new, or mottled color when repaired; and because of the difficulties and costs of repairs when needed; the proper selection of cement-concrete for a wearing surface is of limited application and the especial worth of this material in roadway work lies in its great value for foundations, on which carpets of various kinds may be satisfactorily and economically built and maintained. On the other hand, the high power of concrete to distribute over large areas of sub-grade the strains coming on roadway surface, and the adaptability of a cement-concrete roadway surfacing to its use as a pavement foundation when, under rapidily changing traffic conditions, such a transposition probably will be desired at an early period, justify, under certain local conditions, the selection of cement-concrete as the roadway surfacing. The far larger part of the consideration concerning cement-concrete pavements is composed of two main parts. First, the advisability of providing a concrete foundation for the surfacing, and second, the determination of the character, composition and thickness of the latter. It is interesting to note in this connection, the opinion of some eminent Australian engineers expressed (3) as follows:

"Within the last few years there has been much discussion of the question, whether concrete alone, without a wearing coat of any other material, can be advantageously employed for roadways for vehicular traffic or not, and widely different opinions have been expressed. Where Portland cement is very cheap, as in the United States of America, a rich mixture is warranted, and good results have been claimed, in some cases justly. Some leading engineers recommend 700 lb cement to each cu yd of concrete. There has been but little test of this material for this purpose in Australasia, and the few trial pieces have not, even when covered with a thin carpet coat of bituminous mixture, worn nearly well enough to be considered successful. In general, and especially when a wet mixture is used, the upper surface of the concrete will be mostly mortar, as the coarse aggregate tends to sink, and this mortar has generally been found too brittle to resist abrasion by horses' shoes and metal tires. A bituminous coat, say ¼ to ½ in thick, is not sufficient to take up the shock of traffic, and it generally peels off; then the mortar of the concrete is broken up and ravels, cups are formed, which are soon enlarged and, unless quickly repaired, the road goes to pieces. If the mortar of the concrete is particularly rich in really good cement, and the aggregate is both tough and hard, the surface will last longer. Another difficulty is the cracking due to changes of temperatures. Unless expansion joints are at pretty close intervals the concrete of the roadway is generally found to crack, this leading to the formation of ruts and grooves, which quickly increase in size by the abrasion of their edges. The same abrasion occurs at expansion joints, the filling in, which is necessarily plastic, so that for more reasons than one, road surfaces of concrete alone cannot, for general traffic, be said to have realized the expectations of a few years ago. Even if they had done so, the price of cement in Australasia has been, and is likely to be, too high to warrant their employment, except in special cases. For automobile traffic alone, with the general use of rubber tires, good concrete would be an ideal road crust, but the era of this condition is not yet, and for many a long day shod horses and steel tires will have to be reckoned with. Experience to date has undoubtedly shown that in road-making, the best use for cement-concrete is for foundation courses for wood

blocking, stone paving, or tough bituminous wearing coats, sufficiently thick to absorb the shocks of traffic and to prevent the disintegration of the concrete." See (24a), (24d), (28b), (34a), (35), (41) and (67).

"**Cement-Concrete Pavement Laid for Future Use as a Foundation.** (49c) The city recognized as its problem the construction of a pavement which would not only carry successfully all present traffic, but which, at some time in the future, could be utilized in connection with the development of the road into a city street, as the city was building up rapidly in this direction. Plans had already been prepared for such development, and called for a 66-ft street with 10-ft sidewalks and a 46-ft roadway. It was not thought desirable for the present, however to make the roadway pavement wider than 22 ft, which would be ample for a double line of traffic and allowance for turning out from one line at a time. This 22 ft was laid with concrete pavement, the top surface of which was made parallel to and 2 in below the middle 22 ft of the surface elevation proposed for the street pavement in the final development. When the growth of the city out this road may make it desirable to reconstruct it as a street, the present concrete roadway will be widened by 12 ft on each side, and the whole will then be used as a concrete base and covered with a 2-in layer of stone-filled asphalt. The present pavement is 6½ in thick which will be ample for a foundation for such a wearing surface, even tho it may have lost ½ in or so of material by wear in the meantime."

3. Subgrade

Consideration and the Proper Preparation of the Subgrade before placing the concrete, whether the latter is to itself provide the road surface or whether it is simply to act as a foundation for the roadway surfacing, is very important. In some cases, the roughest kind of preparation of the subgrade has occurred, it being argued that concrete, from its inherent qualities, will render unnecessary any careful work on the natural foundation under it. Economy and efficiency can only be had by carefully providing a suitable subgrade which shall be as even in composition as practicable, and be thoroly compacted and carefully trimmed to the required grades and cross-section. Sometimes the subgrade is rolled even where concrete foundations for pavements of various kinds were to be laid. Where the concrete layer is expected to be subjected to the effects of expansion and contraction, careful trimming up and smoothing of the surface of the subgrade is worth while in order to help minimize the effects of expansion and contraction of the concrete. A lateral movement of the concrete over the subgrade seems to take place, and unless the surface of the subgrade is sufficiently smooth to reduce the friction between the concrete and the subgrade material to such a low point as to permit this movement to be carried to the expansion joints provided in the concrete, there is danger of serious cracks occurring in the concrete between the expansion joints. Further, the proper preparation of the subgrade or base with regard to sufficient drainage is desirable, in order that the concrete layer may not be subjected unduly to strains arising through lack of proper drainage in the base. See (44). In California where much excellent concrete roadway surfacing has been laid, the subgrade is simultaneously compacted and planed just prior to the deposition of concrete on it. A template attached to and moved by the roller results in an unusually even and smooth subgrade which is at the same time made firm and compact.

The Report of Com. IV, 1914 Nat. Conf. Concrete Road Building, included the following recommendations:

"**Natural Subgrade.** The Committee calls attention to the fact that defects in the subgrade of a concrete pavement, or the improper preparation of it, may neutralize or nullify the care given to subsequent stages of the construction. The fundamental requirement of the subgrade is that it shall at all times be of uniform density, so that it will not settle unevenly and cause cracks in the concrete surface. Some engineers

apparently believe that it is not necessary to take as much care in preparing the subgrade or foundation of a concrete pavement as of other forms of roads having an artificial surface, because the concrete slab will act as a bridge over any soft streak or low spot in the foundation; but the Committee is of the opinion that this is a mistake. The strength of a plain concrete slab in acting as a beam to carry the load over a low spot or soft place in the foundation is very slight; and it is so easy to remove the low place or soft spot as not to justify the dependence upon the beam action of the concrete. Any uneven settlement of the foundation of a concrete pavement is nearly certain to cause a crack. With some forms of pavements a crack in the surface will heal under traffic; but a crack in a concrete pavement not only cannot heal under traffic, but will continually enlarge. There is no part of the work of the construction of a concrete pavement that is more worthy of intelligent care and painstaking labor than the preparation of the subgrade; and the slight additional cost necessary to insure good results is abundantly justifiable.

" **New Pavement on Old Road-Bed.** If the concrete pavement is to be constructed upon virgin soil, that is, if it is not to be constructed on an old road-bed, the precautions usually taken, which are described in the specifications to follow, are sufficient to secure a reasonably good foundation. But if the concrete pavement is to be constructed upon an old road-bed of any kind, either an earth or a broken stone or gravel road, great care must be taken in preparing the subgrade. The old road-bed is likely to be more compact in the center than at the sides; and consequently there is danger that the concrete pavement will settle more at the sides than at the center, and therefore will crack longitudinally. Further, it is likely that the travelled way of the old road will not at all places be central under the new concrete pavement, and consequently the latter will settle unevenly and crack. When the subgrade is an old roadway, it is not sufficient to roll the subgrade longitudinally, since the roller is likely to balance upon the more compact central core, and therefore not consolidate the soil at the side of the old roadway. It is not necessary to attempt a detailed description of the method of overcoming this difficulty; but the engineer should be alert to determine whether this condition obtains, and when it does occur, the necessary precautions should be taken to secure a thoro consolidation of all parts of the new road-bed. It may be necessary to add material at the side of the more compact central core of the old roadway. In extreme cases it may be necessary to loosen the old road-bed by spiking or scarifying, and then harrow it, and finally consolidate the entire new road-bed with the roller. The Committee desires to emphatically assert that the need of care in this matter is not imaginary, and that such conditions do really occur in actual practice.

" **Drainage.** The drainage of the road-bed of a concrete pavement is of vital importance. If the subgrade is not well drained, there is danger that, after the concrete is laid, the drying of the soil under the edges of the concrete may permit the pavement to settle and thus cause longitudinal cracks on the surface. Further, if the subgrade is not well drained, there is a possibility that the frost may lift the edges of the concrete roadway and cause a longitudinal crack, at least on the lower side and possibly also upon the upper surface of the concrete.

" **Sprinkling the Road-Bed.** Possibly the following item is more properly included in the instructions for laying the concrete; but it is mentioned here in order that it may not be overlooked. Before the concrete is placed, the road-bed should be thoroly saturated with water. This precaution is particularly important if the ground is dry or the soil is sandy.

" **Rolling the Road-Bed.** The road-bed shall be considered as that portion of the road upon which the concrete is to be placed. The road-bed shall be rolled with a three-wheeled self-propelling roller weighing not less than 10 tons, until every portion of it is firm and hard. When the natural road-bed is so sandy that no consolidation of the soil can be secured, the rolling may be omitted. If soft spots occur in the subgrade, they shall be dug out and the soft material shall be replaced with good earth or other material which will consolidate under the roller." See (50e).

4. Shoulders

There is almost a universal tendency in road construction to keep the width of the concrete low in order to reduce the first cost of the surfacing, and there seems to have been a neglect of proper consideration

of the matter of shoulders. This neglect, in many cases has unquestionably resulted in extravagances and waste in the long run, even if it has secured economy in the first cost. The shoulder maintenance costs generally form no inconsiderable part of the total maintenance cost of a modern road, and it is often real economy to build a pavement wider in order to keep down an annual expense for maintaining the shoulders. The actual width of the concrete roadway to be built should, as indicated in Sect. 4, be made with proper consideration of the traffic conditions to be expected on the road within a reasonable period. Where the concrete pavement is so narrow, that vehicles are almost constantly, in avoiding others, passing from the rigid concrete to the shoulder, serious wear of both the pavement and the shoulder will be found to take place along this line of weakness. This wear is frequently accompanied by the formation of a rut in the shoulder, which holds water in wet weather and thus endangers the foundation of the road. Some of the passing traffic will undoubtedly turn out on to the shoulder further than the rest, but at the extreme outside of the shoulder the travel over it may be so light and infrequent, that the natural material there is not strained beyond what might be called its elastic limit, and hence there is no reason, on this account at least, for its replacement at any extra cost.

The Selection of the Material and Methods for the Construction of Shoulders to a concrete road will therefore be seen to require the use of something between the natural soil, at the outside extremes, and the concrete itself; that the choices are determined by local conditions, such as availability of different materials and methods, width of the concrete road-crust, amount of traffic, etc; and that the wearing abilities or elastic limits of the shoulder material at any point should be outside or above the stresses to be expected at that point. The passage of traffic from the pavement to soft adjacent material can of course be absolutely prevented, and the protection of the edges of the pavement be had by the installation of a raised edging or curb as in the cases of most streets. The necessary reinforcement of the shoulder, where no raised curb is to prevent traffic on it, may be had in various ways. One would, of course, be to widen the concrete pavement to such an extent as to preclude any possibility of traffic going off it. In doing this the center thickness of the pavement need not necessarily be preserved to its edges but the thickness may be tapered down somewhat at the outsides. Or this widening, and tapering down in thickness, of the pavement may be done over a portion of what might otherwise be the shoulder and then the reinforcement continued by the use of macadam or pit-gravel or other materials as may be necessary. Again, the width of the concrete pavement being fixed, the shoulder reinforcement may be had by the construction of bituminous concrete, bituminous macadam, water bound macadam, with or without a bituminous carpet, etc, adjoining the concrete road, all as may be necessary and desirable under the local conditions. See (24b), (50h) and (50s).

5. Crowns, Grades and Thickness

Crowns. The axiom of road building that the flatter the roadway, the greater is the distribution of traffic over it, should be borne in mind particularly with concrete pavements, as their construction lends itself to the securing of low crowns. In the construction of concrete roadways, the effort should be made to secure the lowest possible crown consistent with proper shedding of the water from the surface to the sides of the road. As low as

$\frac{1}{16}$-in rise for each foot of width between the side and the center is generally satisfactory, especially where templates for striking the surface are properly used and the final trimming up of the surface carefully done. In no case, should the crown be permitted to be over $\frac{1}{2}$ in per foot, and even this maximum should be avoided where practicable. It may be difficult to secure as even and perfect a surface under the Hassam method as under the mixing method of laying the concrete, because under the former method, the use of templates is out of the question. Probably $\frac{1}{4}$ in per foot is as low a crown as can be satisfactorily secured under the Hassam method, without the occurrence of slight depressions in the surface which will hold pools of water. These water-holding places may not be in themselves objectionable, but their presence affects the condition of the concrete and can but result in lack of uniformity in its behavior under service. Often the crown and cross-section present the lines of two planes slightly rounded off at their intersection in the center of the roadway, but the provision of circular or parabolic arcs instead of these lines is better, especially in the cases of some city streets where considerations of appearance demand even more effort in this direction. The summit of the crown, or as it is sometimes called the crown, may be moved from the midway line of the roadway if necessary, because of different elevations of the footways on either side, or for other reasons. In the construction of the roadway by the Hassam method, the stone should be spread as in the case of macadam, so that the surface of the stone will form two planes intersecting at an angle. The rolling will then provide all the curvature necessary in the cross-section. Under the mixing method, the templates used will, with the final finishing, determine the curvature satisfactorily.

The Report of Com. XIII, 1914, Nat. Conf. Concrete Road Building included the following on Crowns: See also (50n).

"Unlike some types of pavements, those of concrete are undamaged by water, unless it should find its way to the subgrade. However, since even thin sheets of water or ice on the surface of any pavement are objectionable, a sufficient crown must be provided to insure the unwatering of the pavement. Theoretically, with perfectly surfaced concrete, only a very slight side fall is required to accomplish this. Practical experience in such construction, however, has demonstrated the great difficulty in preventing small imperfections and depressions in the surface, therefore sufficient cross-fall must be provided to insure drainage. The difficulty of accomplishing this is increased because of the suspension of large amounts of dust in the street water. Attention is directed to the fact that on city streets with side curbs we face a different problem from that found in a narrow country road without curbs. In the city street the crown must not only be sufficient to cause the water to run from the center to the side of the pavement, but also enough to insure that an undue proportion of the pavement shall not be covered with water. This requirement is aided if the pavement is given a peaked crown, that is, say $\frac{7}{8}$ of the total rise at $\frac{1}{4}$ distance from center to curb, and $\frac{5}{8}$ at half the distance. The small crown that may be properly used on concrete pavements is justly considered an important merit of this type of pavement. Data have been collected which seem to show that in the case of uniformly thick concrete pavements, the amount of central longitudinal failures has varied directly with the amount of crown. To a lesser extent this would be expected of the other types, thus furnishing an additional reason for the adoption of a minimum crown. In Appendix II will be found the practice regarding crowns in about 30 cities, from which it appears that the minimum crown used on streets is 1/160 of the width of the road and the maximum 1/48. With few exceptions, the crown varies between 1/70 and 1/100 of the width. When the climatic conditions will allow, a crown of 1/100 of the pavement width represents present best practice. The use of the high crowns has in large part resulted from past experience with other types of pavements where high crowns were really required. In future construction, as methods of handling materials are improved and contractors become more experienced, engineers should

not hesitate to specify as low a crown as 1/150 part of the width. Indeed, this has already been done to some extent.

"CROWN FORMULAS. The purposes of this report do not contemplate a discussion of the subject of crown formulas, but a few suggestions may not be out of place. The present common practice of specifying an arbitrary crown ratio for streets varying in width by 75 or more percent, and this, too quite independent of the street grade, does not appear to be founded on any reasonable basis. Unless local conditions forbid, a smaller crown should be designed for a heavy than for a light grade street. Tables have been published which give the allowable crowns as a function of the grades. This whole matter would seem to deserve much more attention that it commonly receives."

Grades. The Report of Com. XIII, 1914 Nat. Conf. Concrete Road Building included the following recommendations:

"The Committee have been unable to find any reliable data on the relative slipperiness of concrete pavements. It is greatly to be regretted that such information is not at hand. In view of the ease with which tests of this nature could be made and the importance of such knowledge in the design or selection of pavements, we recommend to this convention that experiments along this line be undertaken, perhaps such work can best be done under the guidance of some University because of the need of unbiased and impartial tests.

"From such observations as we have been able to make, we see no reasons why a concrete pavement, properly finished, may not be used on grades as steep as any other hard surfaced pavement, and on steeper grades than either wood or asphalt. On steeper grades than 3 or 4% shallow corrugations in the surface will be found of much assistance, in fact, with grades of 5% and over, a real necessity." See (50a).

Thickness. The Report of Com. XIII, 1914 Nat. Conf. Concrete Road Building, included the following conclusions:

"The thickness of the concrete pavement is controlled by many factors, such as condition and character of the subgrade, drainage, traffic, climatic conditions, width of pavement, etc. Three distinct types of cross-sections are in general use.

1. Uniform thickness of concrete for all widths of roadway, and consequently with the same amount of crown in the foundation as in the surface.

2. Roadways in which the concrete is thicker at the center than at the edge but in which some crown is given to the foundation.

3. Concrete roadways in which the concrete is thicker at the middle than at the edge, but which are built upon a flat subgrade. This type seems to be fast gaining in favor.

For a table giving data on the thickness of concrete pavements in this country and some additional information on thickness, see (50n).

"It will be seen from these data that the thickness of concrete pavements varies from 6 to 8 in at the crown line and from 5 to 8 in at the edge. The necessity for the greater thickness is perhaps more urgent in the northern than in the southern parts of the United States, because of the greater extremes of temperature. Because of the growing tendency to increase the size of the loads, it seems reasonable to suppose that the extreme limit of thickness required has not yet been reached.

"Because of the fact that the members of this Committee have had their attention directed chiefly to the conditions obtaining in the northern states, it is not without some misgivings that they suggest the following as conforming to the best practice.

1. Where the width of roadway is not greater than 16 ft, with a porous subsoil, subgrade in good condition and well packed and with loads not exceeding 6 tons, including the vehicle, a thickness of 5 in at the edge of the slab and 7 in at the center is sufficient without reinforcement, using slabs not greater than 16 ft square.

2. On clay soil and the above general conditions, artificial drainage should be provided and reinforcement, ¼ to ½ lb per sq ft, used, placed 1½ to 2 in from top surface; and slabs made not larger than 16 ft square and not less than 6 in thick at edge of slab and 8 at the center

3. Where the roadway is in excess of 16 ft with loads of 6 to 10 tons but with the other general conditions as described in (1), the crown of the pavement should have a thickness of 8 in and the edge 6 in. Under such circumstances reinforcement will usually be considered necessary and economical." See (50n).

Some Tests in Connection with Thickness were made by the Cal. State Highway Comm., especially as regards the abilities of a concrete slab to span successfully under loads trenches or depressions in the subgrade. For a statement concerning these tests and their results, see (49a).

The Relative Advantages of Flat and Crowned Subgrades is a subject of much discussion, but is determined by local conditions. See (29).

MATERIALS

6. Quality of Aggregates

Broken Stone, Gravel and Slag. Broken stone or gravel form the principal coarse aggregates for concrete for road purposes, tho occasionally slag is used. With the use of slag, care must be taken that it is of suitable quality, some slags being so soft and friable as to be unsuitable even when the concrete is acting mainly as a foundation. Some other slags, however, are equal in every respect to the better grades of broken stone, in some cases even making a stronger concrete than the stone, because of the apparent affinity of the slag for the cement. See (28d). Generally in the use of slag, more water is required than in the case of broken stone for making the mixture of proper consistency. The choice between the use of broken stone and gravel depends largely on local conditions. Ordinarily, gravel when mixed into concrete will produce a concrete of slightly greater cross-breaking and crushing resistance than broken stone, probably because the rounded particles of the gravel permit and result in a denser concrete in the ordinary methods of the mixing and placing than is obtained with the angular fragments of broken stone. A mixture of 35 to 50% gravel with 65 to 50% of broken stone will, under the ordinary mixing methods, give an even stronger croncrete than either gravel or broken stone alone, probably for the same reason, and coarse gravel which has been run thru a crusher and thus broken up to some extent, will give a concrete about equal in strength to the mixture of gravel and broken stone referred to above. Tests made in the laboratory of the Md. Geol. Survey in 1905 and 1906 on 4 in concrete cubes made from mixtures in the same proportions of sand, cement and broken stone, the same sand, cement and gravel, and the same sand, cement and a mixture of the gravel and broken stone, showed the ultimate crushing strength to be in the order named, and furnished the foundation for the foregoing remarks. If the concrete is made of gravel and is exposed directly to the traffic, the tendency of the rounded gravel stones to be dislodged from the mortar surrounding them has been noticed, and this seems to exist to a greater degree than is the case with angular broken stone. On the other hand, the gravel being usually made by natural forces from the harder varieties of rock, generally exhibits a greater resistance to wear than many of the rocks crushed and used for concrete. See (28c) and (50d). Slag and trap rock concrete gave under comparative tests at Columbia Univ. an average compressive strength of 2465.5 lb per sq in for the slag and 1975.5 lb for the trap rock concrete.

The Report, Com. III, 1914 Nat. Conf. Concrete Road Building (50c) **was, in part, as follows:** "Tentative specifications for aggregates are given at the end of the report. Simple rules covering the most essential requirements are as follows:

1. For fine aggregate, use only sand or other fine aggregate that has been actually tested for mechanical analysis and tensile strength of mortar, and is free from fine particles.

2. Use coarse grained sands or hard stone screenings with dust removed.
3. Use sand or other fine aggregate that is absolutely clean.
4. For coarse aggregate, use hard stone, such as granite, trap, gravel, or hard limestone.
5. If bank gravel or crushed stone is used, always separate the sand or screenings and re-mix in the proper proportions.

"If local conditions prevent following any one of these rules, adopt some other material than concrete for your pavement.

"Briefly taking up each one of these points:

1. Actual laboratory tests are necessary for fine aggregates, because it is impossible for the most expert builder to always distinguish by appearance between good and poor sands. Sand may be coarse, of good color, well graded, and apparently perfectly clean, and yet because of a minute quantity of vegetable matter may show practically no strength when made into mortar or concrete. See (20a).

2. Coarse sand is necessary not only for strength and density, but to prevent the formation, on or near the surface, of a layer of fine material, consisting of a mixture of dust and cement which has no durability. Mortar made with fine sand or sand having a large proportion of fine grains of silt, hardens slowly and is especially objectionable in cold weather. This prevents its attaining proper strength before the road is thrown open to traffic. A sand having a considerable proportion of fine particles may possibly show high briquette tests, and yet the mortar not have good resistance to attrition or wear.

3. Sand must be absolutely free from vegetable or organic matter, or it is liable to harden not at all or too slowly to be serviceable. Frequently, sand may be entirely satisfactory in appearance, and yet be worthless for concrete.

4. A coarse aggregate of hard quality is necessary to resist the wear and abrasion of hoofs and wheels. Failures of concrete roads have been caused simply by the softness of the coarse aggregate. In one instance, for example, shells were used for the aggregate, and the road went to pieces as soon as it was subjected to wear. See (60). All stone, like shale, slate, shells, and soft limestone, must be rejected; while trap, granite, and conglomerate, are especially suitable materials. A hard limestone, such as that occurring in certain localities along the Hudson River, which is sold in New York as trap rock, is satisfactory for concrete roads. A hard limestone cannot be cut with a knife and the specific gravity is high, say, over 2.70. Gravel does not bond quite so strongly with cement as does broken stone. When properly screened and free from dirt, however, and remixed with sand in the proper proportions, a good surface can be made even for a 1-course pavement.

5. Many roads that are now being built will prove worthless because of the use of sand taken directly from the bank without screening. If the gravel contains as much as 40% of stones and very rich proportions are used, say 1 part cement to 3½ parts bank gravel, a fair concrete can sometimes be produced, but it is always cheaper in such cases to screen the gravel and remix the sand and stone in proper proportions. There will be, for example, a saving of ¼ barrel, or 1 bag, of cement per cubic yard of concrete by using proportions 1 part cement to 2 parts sand to 3 parts screened gravel, instead of using the unscreened bank gravel in proportions 1 to 3½. This difference will more than pay for the additional cost of screening the sand and rejecting part of it. At the same time, the result will be more uniform and the surface more durable because of the stones which take the wear. When an excess of sand is used in the mixture, as is the case with run-of-the-bank gravel, the mortar rises to the top when the concrete is placed and the wearing surface is less resistant than a mix that is uniform thruout."

7. Proportions of Aggregates

Various proportions of the aggregate, cement and water are used or contended for. In the majority of cases, some arbitrary formula is generally followed, but this practice is of extremely questionable value. If it is to be expected that within a relatively short period, the concrete roadway is to be covered with a bituminous carpet, or other protecting surface, there certainly are serious objections to providing a richer and more ex-

pensive mixture and to using a larger proportion of cement than is necessary to give sufficient crushing and cross-breaking resistance in the concrete under the loads to be carried by the concrete as an artificial foundation. On the other hand, if no protective coating is to be provided on the concrete, it may be necessary to make the mixture sufficiently rich in cement, as will enable it to resist to the utmost the destructive effects of traffic coming directly on it. Between these two extremes, various proportions in the mixture are possible, and the exigencies of the particular case should be carefully considered when the decision as to the proportions is to be made. Further, with regard to the amount of cement to be used in any case, it is now generally recognized that the carrying power of various materials for cement, differs considerably. That is, some kinds of material require more cement in the mixture to give the same strength than do others, and a similar remark may be made in regard to the cement itself. Some cements seem to go further than others when used with the same aggregates. For concrete pavements exposed directly to traffic without the protection of a carpet of any kind, as much of the coarser aggregate as possible should be secured in a given area of surface of the road, in order that the greater part of the wear from the traffic shall be borne by this aggregate and not by the mortar or cement. On the other hand, where the wear of traffic is to be taken up by a carpet and the concrete layer is to act mainly as a foundation for the carpet, the proportion of coarse aggregate should be that which will give the greatest sustaining power to the concrete mixture, regardless of the grinding or hammering effect of the traffic. Reference to Sect. 2 will be advisable in this connection for information concerning the manufacture of hydraulic cement and its characteristics. N. C. Johnson (42), gives important information concerning concrete, thru the use of microscopic tests demonstrating conclusively the need for proper mixing of the ingredients, proper hydration of the cement and proper proportions for all of the materials used, and pointing out that an excess of cement not only does not add proportionately to the strength of the concrete but actually weakens it in many cases. This is particularly true where concrete is used for roadway surfaces. See also (24c), (50o) and (69b). The amount of water necessary for concrete road construction will of course depend on local conditions, weather and other factors. It has been variously estimated, at from 50 to 250 gal per cu yd of concrete. See (26d) and (50l).

Hydrated Lime is sometimes added in the mixing or used to replace a portion of the cement that would otherwise go into the mixture, and the amount of lime so used is generally about 10% of the amount of cement. The addition of hydrated lime to Portland cement mortar or concrete is not new, but the application of the idea to some forms of concrete work has not been given as much attention as necessary to develop all the possibilities. The waterproofing feature of the addition had been dwelt upon to some extent but the other apparent advantages to be had from the addition, such as those coming from the increased plasticity of the wet concrete, have generally been ignored. See also (8), (14), (34b), (65) and (68). Where concrete is to be delivered by the spouting method the low angle of slope requires an excessively wet concrete to insure easy spouting, and yet excessively wet concrete is undesirable for many reasons. The addition of hydrated lime, by its giving the greater plasticity to the concrete, reduces the necessity for water in excess, and would in many cases permit of satisfactory spouting of the concrete on a flatter slope. Another point in favor

of the use of lime in concrete pavements is an apparent effect of the hydrated lime to reduce the tendency to segregation in the wet mortar of sand, cement and stone. A further effect of the addition of lime and one particularly appreciable in highway work is the reduced susceptibility of the resulting concrete in the matter of expansion and contraction of this mass, and therefore a reduction in the cracking so often objectionably evident in concrete roadways. In laying a concrete roadway, it is important to have the concrete wet enough to permit its being readily and properly compacted to form a mass with a minimum of voids, and yet when so wet to avoid segregation. The addition of hydrated lime seems to decrease the tendency of the cement and sand to separate and at the same time to make the mass more readily compact. Lime mortars are usually softer than cement mortars, and there is some question, which can only be answered by experience, whether or not the addition of the lime will result in an unsatisfactory degree of hardness in the mortar for concrete roadways, especially as extreme hardness and resistance to concussion and abrasion are of greater importance for the concrete in roadways than in most other places where it is used. Thoro mixing of hydrated lime with the cement is important as otherwise a lack of homegeneity with its highly unsatisfactory consequences will result. See (27a) and (36).

Density and Strength. The proportions of the various ingredients should, in order to give the greatest possible strength to the concrete roadway, provide the greatest density for the concrete. With the use of varying kinds of aggregate, it will then be necessary, in order to secure the greatest density, to determine accurately the irreducible voids in each kind of aggregate and to proportion the ingredients accordingly. That is, the voids in the fine aggregate should be accurately determined and sufficient cement provided to fill the voids. Usually it is best to allow a slight, say 5 to 10%, excess of cement for the actual voids to be filled so as to make up for any unavoidable loss or waste in manipulation. Having determined the irreducible voids in the coarse aggregate, provide such an amount of mortar as will fill these voids, also allowing a slight excess in the mass of mortar for the voids in the coarse aggregate. Any use of hydraulic lime may be considered either as part of the cement to be used or as the excess of cement referred to.

Moyer (47) states that "Maximum density, other things being equal, gives maximum strength. Arbitrary specifications, without previous knowledge of the character of aggregates to be used, are wrong, and the stated proportions are meaningless. Various sizes of stone should be used for purposes of economy and for obtaining the greatest density and strength." See (12), (13), and (49b).

The Usual Practice in Making a Mixture is to assume arbitrarily certain proportions for the cement, fine aggregate and coarse aggregate, and in most cases to use far more cement than is necessary or desirable.

The Report, Committee XIV, 1914 Nat. Conf. Concrete Road Building included the following: See also (50o).

Variations in Local Conditions. "Any specification for proportion and consistency of materials for concrete pavement must be general and suggestive, rather than mandatory, adaptive, or rigid. The representatives at this conference come from all parts of the country, from districts whose geological formations furnish concrete materials differing widely in their physical and chemical composition, and also furnish soils of equally wide characteristics upon which these pavements are to be laid. A rule that may be admirable for a granite district, furnishing hard cubical well graded rock, may fail utterly if applied to a district whose only resource is soft limestone or gravel that washes into shape instead of fracturing into sharp angled cubes. Ideal paving concrete is a combination of perfect mineral aggregates and cement in such proportion

as will give the greatest possible density, and in which, for economical considerations, the cement content is the least possible consistent with ultimate strength and durability. Relative cost of material may justify greater thickness of base with less crushing or tensile strength per unit area.

Proportions of Ingredients of Concrete. "For the base of TWO-COURSE PAVEMENT, with sound hard limestone or gravel having 40% voids, screened washed bank sand having 30% voids, and Portland cement passing the standard specifications of the Am. Soc. Test. Mat., the proportions should be 1 sack of cement, 2½ cu ft of sand and 5 cu ft of crushed stone or gravel, the aggregate having been so proportioned as to eliminate the voids as far as practicable.

"For ONE-COURSE PAVEMENT the proportions should be 1 sack of cement, 2 cu ft of sand and not more than 3 cu ft of crushed stone or gravel.

"**Consistency of Concrete.** The amount of water should be such as to make the concrete plastic and still retain its shape, such as is commonly called a quaking mixture. Methods and distance of transportation before depositing will be factors in determining the amount of water used. Concrete deposited from buckets, travelling along a boom, may have more water added than when wheeled for a considerable distance in barrows or carts. In the latter case, the unavoidable shaking brings the lighter materials to the surface and causes a segregation of the materials, which results in an improper mixture when deposited.

"**Proportions of Wearing Course.** The fine aggregate for wearing course shall be mixed with Portland cement in the proportion of 1 sack of cement to 2 cu ft of the graded mineral aggregate. While this furnishes a considerable excess of cement, greater impermeability is secured.

"**Consistency of Wearing Course.** Sufficient water shall be used with the fine aggregate to form a mortar that will work easily under the template and at the same time retain its shape when deposited."

8. Mixing Cement-Concrete

Mixing the Ingredients for the Concrete in a Machine designed for the purpose and then placing the prepared mixture on the subgrade made ready to receive it so as to give the thickness, grades and cross-sections desired, is at present the more usual method of constructing concrete roadways. Attempts have been made to roll the concrete after so placing, and they have been more or less successful. See Art. 14. Various makes of machines for mixing the concrete and different contrivances for conveying it from the machinery to the road-bed are in use, each claiming some special advantages. The desirable points for such machines are uniformity of mixing, rapidity of work consistent with uniformity, ease of cleaning, convenience of operation and reasonable cost of operation, and ease of movement from place to place on the road. For conveying and placing contrivances, it is necessary that they be flexible, and that they shall prevent, insofar as practicable, any tendency of the concrete mixture to segregate.

The Report of Committee XI, 1914 Nat. Conf. Concrete Road Building includes the following recommendations: See also (501).

"In the construction of concrete roads, probably no really important part of the work is given less consideration, in specifications and in the field, than the actual mixing and placing of the concrete. The following notes, based upon observations in field, and the results of tests, were prepared with a view of pointing out the difference between good and bad practice, and to serve as a basis for recommendations covering this phase of the work.

"**The Mixer.** The concrete mixer should be of the batch type provided with an automatic water tank, traction drive and power loader. Mixers having a boom and bottom dump bucket of sufficient size to convey one complete batch for placing the mixed concrete, are preferred. However, buckets of other types and sizes, open troughs and revolving tubes can be used, and will give good results. An abuse of the

revolving tube distributing method lies in operating batch-mixers so equipped as continuous mixers, the supposition being that as the tube is provided with blades and revolves, the materials are mixed in the tube. This tube serves only as a conveyor and cannot to any degree take the place of or serve as a mixer. Concrete cannot be successfully conveyed or delivered thru a trough or spout, thru which it must flow by gravity, for if it is mixed to a consistency such that it will flow at the required angle, the concrete will be too wet for the best results. The mixer should be provided with a suitable automatic water tank which can be quickly filled and emptied, so that when once determined, the required amount of water can be added to each batch of concrete. A number of so-called automatic tanks on mixers are not satisfactory owing to their limited capacity, delay in filling and emptying, and to the fact that they depend, for successful operation, upon a constant water pressure. Water is pumped on most road jobs, with small gasoline or steam pumps, and it is not possible to maintain uniform pressure in the feed line. An automatic measuring tank of the required capacity, that may be emptied quickly, connected by means of a comparatively large pipe, with an auxiliary or storage tank of about 50 gal capacity, would be more satisfactory than the one tank system commonly used. Where necessary to keep from cutting up the subgrade and to facilitate moving, the wheels of the mixer should be run on suitable planking. Material of good quality, 3 in thick by 10 in wide, in comparatively short lengths, with square ends, will be found satisfactory for this purpose. The power loader or skip should be of sufficient size to hold all the materials required for the batch. In charging the skip a part or all of the coarse aggregate should be placed first, and the cement, fine aggregate, and remaining coarse aggregate, if any, on top of this. All the cement should be in the skip before the last of the aggregate is added. If charged in this manner there will be less tendency for the materials to stick in the skip when emptying and less loss of cement on windy days. A systematic method of loading the skip will also serve as a check on the right amount of material being placed each time. The filling of the skip is accomplished in practice in two ways; by the use of wheelbarrows and by shoveling direct from the supply piles into the skip. This latter practice, however, should be discouraged, for accuracy is impossible, and it encourages carelessness. Besides, the entire loading gang loses time waiting, while the skip is raised and lowered.

" Mixing Concrete. No important operation is given less attention than the mixing of the concrete. Frequently in practice, the time the materials remain in the drum is governed only by the speed of the gang charging the skip. At times the batch mixer is operated practically as a continuous mixer, by fastening the discharge scoop or spout so that there is a constant flow of concrete from the mixer. The quality of concrete is largely dependent upon thoro mixing. To insure thoro mixing, the revolutions per minute of the mixer and the time the complete batch, including water, remains in the mixer, should be specified. To specify either the revolutions per minute or the time, is not sufficient as is plainly shown by the following tabulations of field observations:

Job	Mixer	Rev per Min	Mixing Time
1	Smith	10	1½ min
2	Koehring	18	40 to 45 sec
3		18	30 sec
4	Foote	14	45 sec
5	Eclipse	13	2 min
6	Austin Cube	16	50 to 55 sec
7	Smith	11	2 min
8	Chicago	24	30 sec
9	Foote	18	25 sec
10	Koehring	18	20 sec
11	Austin Cube	16	20 to 60 sec
12	Koehring	32	15 sec
13	Austin Cube	16	10 sec
14	Ransome	7	1 min
15	Koehring	18	20 sec

"Upon inquiry of the manufacturers it was found that the revolutions per minute of the drum of batch mixers varies for different makes and for different sizes of the same make, as shown by the following table compiled from data furnished by the manufacturers:

CAPACITY AND SPEED, REVOLUTIONS PER MINUTE, OF PAVING MIXERS

Name of Mixer	Rated Capacity Cu Ft Unmixed Material	Capacity Bags of Cement in 1 : 2 : 3 Mix	Rev per Min of Drum	Name of Manufacturing Co.
Austin Cube	14	2	18	Municipal Engineering & Contracting Co.
	22	3	18	
Chicago Mixer	10	1	15	Chicago Concrete Machinery Co.
	14	2	12	
	23	3	11	
	30	5	10	
Smith Mixer	14	2	14	T. L. Smith Co.
	24	4	12	
	33	5	11	
Foote Mixer	7	1	18	Foote Concrete Machinery Co.
	13	2	16	
	23	3	14	
Koehring	7	1	20	Koehring Machine Co.
	12	2	17	
	20	3	16	
	24	4	15	
	30	5	15	
Oshkosh	18	3	18 to 20	Oshkosh Manufacturing Co.
Milwaukee	8	1	20	Milwaukee Concrete Mixer Co.
	14	2	18	
	20	3	18	
Ransome	8	1	21	Ransome Concrete Machinery Co.
	10	1	21	
	18	3	20	
	21	3	20	
	24	4	17	
	28	4	17	
Standard	7	1	16	Standard Scale & Supply Co.
	15	2	14	
	21	3	14	
	30	5	13	
Chain Belt	10	1	20	Chain Belt Co.
	15	2	18	

"Because of the shape and arrangement of the interior of the drum, the rate at which a given mixer is operated has a direct bearing upon the quality of the concrete, therefore the drum should be operated at approximately the speed at which the manufacturer claims the best results would be obtained. It is recommended that all specifications contain a clause to the effect that all the materials in any one batch, including the water, should remain in the drum of the mixer at least 45 sec before any of the concrete is discharged. In all cases the drum should be completely emptied before the next skip of materials is dumped into the mixer. This is a source of constant controversy between the engineer or inspector and the contractor, especially where the mixer used is equipped with an open trough, or with a boom and bucket when the bucket is not large enough to hold the whole mixed batch. The operator should start the water into the drum as soon as the skip is in position to dump, that is, it is not necessary to mix materials dry before adding water. See also (50 l).

" Consistency. The practice on road work is to mix concrete entirely too wet. This causes a separation of the coarse materials from the mortar, resulting in stony pockets thruout the concrete. Where the concrete is mixed too wet, it is practically impossible to obtain and hold the required crown, and stony patches frequently appear on the surface after it has been finished, owing to the flow of water and mortar to the sides. In striking off and floating concrete mixed with an excess of water, it is also practically impossible to obtain a surface of the desired character, as the excess of water collects in and hides depressions and other inequalities in the surface, which

cannot be corrected as they are not apparent until after the water has evaporated. In addition to the difficulty encountered in getting wet concrete into the pavement in a manner which will give the best results, laboratory tests and results observed in the field show that, other things being equal, a wet mixture is of inferior strength and quality to concrete of a medium wet consistency. The marked effect in the strength of concrete that a variation in the consistency produces, is shown in the following table of results of tests made in the Sheffield Scientific School of Yale Univ. by Robinson. See (54).

Percent Water	7 Days†	30 Days*	60 Days†
20.	2052	2777	3194
22½.	2173	3132	3305
25.	2277	3278	3388
27½.	2500	3516	3597
30.	1722	2874	3166
32.½.	1413	2416	2666
35.	1222	1977	2388
37½.	1097	1819	2173
42½.	652	1500	1888

*Average of two tests. †One test only.

"In this test water was added from 20 to 42% according to the following method: As a minimum, enough water was taken to moisten the stone and sand, and then there was added 20%, of the amount of the cement by weight, water. Each subsequent mixture was increased by 2½% water. It was noted that the 42½% mixture was about as wet as is used in the average wet mixture, tho drier than some slushy mixes.

"As yet, there is not sufficient data on which to base a definite conclusion relative to the influence of the consistency of concrete upon the expansion and contraction; however, information at hand seems to show that this action is influenced very largely by the consistency. Owing to the methods employed in striking off and finishing the surfaces of concrete pavements, there is little likelihood of mixing the concrete too dry. Concrete mixed with an excess of water is easier to mix, to handle, to place and to finish, than concrete of the proper consistency, which explains the tendencies toward wet mixtures. The amount of water in the concrete should be such as to cause it to settle to a flattened mass when dropped from the bucket, but not sufficient to cause it to flow readily on the subgrade. The consistency should be such as not to require tamping, but not so wet as to cause a separation of the mortar from the coarse aggregate in handling and placing. If there is an excess of water on the surface, or the mass has a tendency to flow or settle out of position after being floated, the concrete has been mixed too wet."

The Report of Com. VIII, 1916 Nat. Conf. Concrete Road Building (50 l), says . . . "your Committee believes that with the average amount of moisture found in concrete materials, the water to be used in a proper mix for concrete used in road making should not exceed 6 lb per cu ft of material, this meaning the cement, sand and stone used, measured loose. This is approximately 1 gal of water for each cubic foot of concrete in place. Dry materials in hot weather require more water, and rain soaked sand and stone require less water. The most needed reform in the mixing and placing of concrete for roads is less water than is generally used."

Proportion of Water. Fletcher correctly states that a variation in the proportion of water used in the mixes is largely responsible for inequalities in both the character of the concrete and its evenness of surface, and that no matter what mechanical contrivances exist for controlling the supply of water in the several batches, the operation of the machines will vary and the results will be unsatisfactory. Ponding for curing the concrete is therefore advocated as effective for curing and also for compensating the inequalities of the water in the different mixtures. See Art. 14.

Duration of Mixing. Uhler states (68) that "Every batch of concrete is mixed for 1½ min; the reason for this being that a number of experiments, made during the progress of the work, indicated that the greatest strength, commensurate with economy in cost of mixing is obtained from a mix of this timing. The experiments which resulted in this conclusion were as follows:

½ min mix, 9 rev, 8 day test, 1400 lb per sq in,
1 min mix, 17 rev, 8 day test, 1587 lb per sq in,
1½ min mix, 26 rev, 8 day test, 1924 lb per sq in,
2 min mix, 35 rev, 8 day test, 1661 lb per sq in,
3 min mix, 51 rev, 8 day test, 1673 lb per sq in.

This shows that if these results are plotted, the curve would break between the 1½ and the 2-min periods. If the accuracy of the results on the 1½ min mix be questioned, and this figure assumed to lie between 1587 and 1661, the results plotted so as to form a curve will show that the rate of increase in strength decreases with increase in the time of mix, and the increase obtained from the 2 and 3 min periods is scarcely worth the additional time and cost involved."

9. Tests of Cement-Concrete for Pavements

Essential Properties. The most important requirement in concrete for roadways is uniformity, and this is also one of the most difficult to obtain. In the operations of mixing and placing concrete, there is always present a tendency toward segregation of the mortar and different sizes of aggregate which results in pockets, or areas of different composition thruout the concrete layer and more especially in its surface. It is evident that the resistance to the effects of traffic will be unlike in different areas, and a serious danger exists of lack of uniformity in wear. The results of non-uniformity are holes in the surface and irregular cracks thru the mass. This means that the surfacing of the worn concrete with other materials will have to be begun at an earlier date than would otherwise be the case if uniformity of wear were had, to say nothing of the increased cost of repairs to the original surface in the meantime. See (59). High resistance to the forces tending to produce expansion and contraction in the concrete is another desirable quality in the concrete roadway. This is especially important where the concrete is not covered by a protective coating and the forces referred to have the greatest opportunity for action, while the effects of such action are also most appreciable. It is believed that the greater the density of the concrete, the higher the resistance to expansion and contraction. An effort has been made to test concrete for the qualities involved in its use for roadways at the University of Minnesota, but the machine used in the test has not been standardized, nor has the work with it progressed far enough to show its qualifications sufficiently to recommend its adoption for standard testing purposes. See (43).

Field Samples of Cement-Concrete. Method recommended by First Conference, 1917, State Highway Testing Engineers and Chemists.

"**When Taken.** Samples shall be taken regularly, for the general control of strength and uniformity on 1 day of each week of work; and at irregular intervals, whenever a complete change is noted in the character or grading of one or more materials or in any element affecting the entire mix.

"**Number of Samples.**

1. In taking regular samples three specimens should be molded to be broken one at each of the periods, 14 days, 28 days, and ....

2. In taking irregular samples, nine specimens should be molded, three to be broken at each of the periods, 14 days, 28 days, and ....

"**How Taken.** The batch sampled for general purposes should be similar in consistency and general grading of the aggregate to the regular run of batches being turned out. The sample from which specimens are molded should be composed of several portions taken during the discharge of one batch in order to represent an average of the batch; or the batch may be dripped upon the subgrade and concrete from several points, taking care to exclude dirt, placed in a clean wheelbarrow or other container, avoiding additional mixing."

Tests of Field Samples of Cement-Concrete. Method recommended by First Conference, 1917, State Highway Testing Engineers and Chemists.

"**Form of Specimen.** The test specimen may be a cube, a prism or a cylinder, but it is felt that a cylinder 6 in in diameter by 12 in high will give the most satisfactory results. Molds of all types can be successfully used, from the most permanent to those which can be used only in forming a single specimen.

"**Molding Specimens.** The molding should be done as near the mixer as practicable, and the concrete should be conveyed to the molds with as little jarring or mixing as possible. The molds should be placed on a flat, non-absorbent surface, and the concrete should be placed in layers of .... inches, with slight puddling by means of a ½-in steel rod.

"**Storing.** Specimens should be permitted to remain in position where molded for a period of 24 hr. At the end of that period they may be stored on the completed concrete pavement, buried in the same covering material, and moistened at the same intervals, until ready for shipment to the laboratory; or, if not considered practicable to store on the completed concrete, they may be covered at the point of molding with the same covering material as used for the concrete pavement, and moistened at the same intervals, until shipped to the laboratory.

"**Shipment.** Specimens must be suitably protected from injury during shipment.

"**Testing.** Specimens should be capped with mortar shortly after molding, or with plaster of Paris just before testing, so as to provide plane bearing surfaces. The plane surface is formed by placing the specimen on a flat, non-absorbent surface and pressing a flat plate on the soft mortar or plaster cap. In testing, the specimens are mounted in the testing machine with spherical bearing block placed on top of the specimen, the capped specimen being placed in direct contact with the steel bearing surfaces.

Compression Tests. Uhler states (63) that "Another feature that has been brought out in connection with this work is the great variation in strength of 6-in cubes of the regular mix, made up daily during the progress of the work, and set aside for testing at periods of 7, 14 and 28 days and 6 months. The 7-day compression test runs from 1065 to 3635. The 14-day test, from 1572 to 4212. The 28-day test, from 2862 to 5361. As yet, no 6-month breaks have been made. These wide variations in strength values may be due to a combination of several causes, including variations in the quality of the cement and mineral aggregates; difference in storage temperature, some of the specimens having been made up during warm weather and some during very cool weather; possible slight differences in the mix, and differences in the molding and compacting of the specimens; and finally, the unavoidable experimental variations in making and breaking the specimens. Since every one of these factors, except the last named, enter into the actual construction work, the importance of systematic testing of the cement used, examination of the sand and stone, particularly with reference to grading, and strict adherence to uniform, approved methods of mixing, placing, compacting and curing the concrete in the pavement, are forcibly demonstrated by the range in these daily strength values."

Rattler Tests by Roman (58). "The experiment consisted of preparing blocks of concrete, mortar and cement of a standard paving brick size, 3½ by 4 by 8½ in, and submitting them, when 90 days old, to the rattler test for paving brick. The same cement was used in the preparation of all of the blocks, and the same sand was used in the mortar and concrete blocks. The quantity of water used was such as to give a cement paste of normal consistency for the cement blocks, and such as to give mortar and concrete which could be floated without tamping, but which were not so wet that they would flow readily. The mortar blocks were made of 1 part cement and 2 parts sand, and the concrete blocks of 1 part cement, 2 parts sand and 3½ parts gravel or crushed stone. All measurements were by weight. The blocks were kept under wet sacks for 1 week and after this period they were sprinkled with water once a week. The blocks were all tested in the rattler at the age of approximately 90 days, after they had been air dried for 1 week. The rattler used was a standard paving brick rattler as recommended by the Nat. Paving Brick Mnfrs. Assn., rotated at the rate of 30 rev per min. Ten blocks were taken for each test and a standard charge of 300 lb of cast iron shot used. In order to follow closely the effect of this abrasion test, all the blocks were submitted to repeated rattler test of 900 rev each. Ten paving bricks, representing 5 brands of blocks used on State Aid roads in Illinois, were submitted to a similar test. Each block was marked in such a way that it could not be identified during the entire experiment.

"While no definite conclusions can be drawn from these tests as to the relative wearing qualities of brick and concrete, yet the results obtained appear to bring out the following facts, which have a bearing on concrete road construction:

1. The advisability of using rather small aggregates in one-course concrete road construction. This will tend to insure more uniform wear and a smoother surface.

Table II.—Showing Total Losses in Percent by Weight of Blocks

Revolutions of Rattler	900	1800	2700	3600
Mortar Block No. 1	22.0	39.7	53.0	64.7
Murtar Block No. 2	22.6	39.6	52.3	63.9
Mortar Block No. 3	23.0	41.2	54.2	66.5
Mortar Block No. 4	23.1	40.8	54.1	66.2
Murtar Block No. 5	24.2	42.5	55.8	68.3
Mortar Block No. 6	21.2	37.8	50.3	61.7
Mortar Block No. 7	20.2	37.5	49.8	61.7
Mortar Block No. 8	22.8	41.5	55.0	66.9
Mortar Block No. 9	25.5	45.6	59.4	72.3
Mortar Block No. 10	27.0	47.8	62.7	75.5
Average percent loss of mortar blocks	23.2	41.4	54.7	66.8
Concrete Block No. 1	34.4	54.2	79.5	....
Concrete Block No. 2	34.3	55.2	73.5	....
Concrete Block No. 3	39.5	61.9	76.9	....
Concrete Block No. 4	38.1	60.8	78.5	....
Concrete Block No. 5	41.3	63.4	69.2	....
Concrete Block No. 6	34.5	50.4	62.0	....
Concrete Block No. 7	42.9	63.3	broken	....
Concrete Block No. 8	32.0	49.7	65.2	....
Concrete Block No. 9	36.2	54.2	70.0	....
Concrete Block No. 10	32.2	50.7	65.1	....
Average percent loss of concrete blocks	36.5	56.4	71.1	....
Average percent loss of crushed stone concrete blocks 1 to 5 inclusive	37.5	59.1	75.5	....
Average percent loss of gravel concrete blocks 6 to 10 inclusive	35.7	53.7	65.6	....
Paving Brick D No. 1	12.4	17.8	23.1	28.5
Paving Brick D No. 2	11.8	16.4	20.5	24.0
Paving Brick P No. 3	16.4	24.2	29.4	34.2
Paving Brick P No. 4	15.2	21.8	27.6	30.7
Paving Brick A No. 5	12.1	17.6	22.6	26.6
Paving Brick A No. 6	12.1	22.2	29.7	36.1
Paving Brick S No. 7	11.3	broken	....	....
Paving Brick S No. 8	16.5	21.4	26.7	30.3
Paving Brick B No. 9	16.5	24.1	31.2	38.6
Paving Brick B No. 10	12.3	20.2	24.7	28.3
Average percent loss of paving brick	13.7	20.6	26.2	30.8

NOTE. D No. 1, and D No. 2, Danville Blocks; P No. 3 and P No. 4, Poston Pavers; A No. 5, and A No. 6, Albion Shale Blocks; S No. 7, and S No. 8, Springfield Blocks; B No. 9, and B No. 10, Barr Blocks.

2. The apparent advantage as far as wearing qualities are concerned of the 2-course method in concrete road construction. A rich mortar or fine aggregate concrete could thus be used for the surface course, insuring much better wearing qualities. At the same time, a lean concrete, or aggregates of rather poor quality, could be used for the lower course and the resulting cost of the road would probably be less than the cost of the one-course concrete pavement, as built at the present time.

3. The disadvantage of using a very wet concrete or of excessive floating of the concrete, both of which have the effect of bringing to the surface of the road a layer of neat cement. The above tests show that neat cement will not stand impact and will rapidly be worn off under traffic. It seems probable that some of the depressions which form on concrete pavements are due to the wearing of neat cement as well as to the formation of stone pockets."

Rattler Tests by Abrams (11). "The machine used is a brick rattler of the Talbot-Jones type. The concrete tested is molded into blocks with square, 8-in faces and depths of 5 in. The 10 blocks constituting a test set are arranged around the perimeter of the drum and held in place by wooden wedges, the faces toward the inside forming a 10-sided polygon. The abrasive charge consists of about 200 lb of cast iron spheres, ten 3¾ in in diameter, and the remainder, about 133, 1⅞ in in diameter. These are

placed inside the rattler and the end of drum covered with a heavy wire screen. The test consists of the exposure of the blocks to the action of the spheres in the revolving drum for 3600 rev at a rate of about 30 rev per min. The loss in weight of the blocks has varied from 8 to 25%. The advantages which this method of testing is believed to have are as follows:

1. The concrete is subjected to a treatment which approximates that of service.
2. The test piece is of usual form and of sufficient size that representative concrete can be obtained.
3. The test pieces are convenient to make, store and handle, and require a relatively small amount of concrete.
4. The cost of the test is not excessive.
5. The machine used is found in numerous testing laboratories.
6. The wearing action takes place on the top or finished surface of the concrete. This makes it possible to study the effect of various surface treatments or finishes.
7. Several tests may be made at the same time, thus enabling more representative results to be obtained.
8. Tests may be made on sections of concrete cut from roads which have been in service.
9. Other paving materials such as brick, granite blocks etc may be tested in the same way as concrete."

Friction Tests of Cement-Concrete Pavements on Various Types of Subgrades (33). "The bases of concrete roads built in the past have been of varying character. Loam, clay, old macadam, gravel, sand and many other kinds of material support the concrete, and some offer more frictional resistance than others. In laying out the present series of tests, therefore, cognizance was taken of this fact and several different bases were used. Shallow ditches 6 in deep, 3 ft wide and 7 ft long were first dug in the soft clay soil of the Arlington Experimental Farm belonging to the U. S. Dept. of Agr. Filling material forming the subbase was then deposited under the supervision of a trained road engineer, tamped solidly and smoothed, or otherwise treated in readiness for the placing of the concrete. A 1 : 1½ : 3 mixture was used, machine mixed to a medium wet consistency, and the slabs cast were 2 ft wide by 6 ft long and 6 in thick. The various subbases prepared were as follows: (1) Clay, smooth top surface; (2) clay with cobblestones partly rolled in surface; (3) broken stone, ¾-in to dust, flat top surface; (4) concrete base, top surface, troweled smooth; (5) loam, smooth top surface; (6) sand, top surface smoothed and oiled with heavy flux oil; (7) clay, surface scored to make it uneven; (8) gravel, ¾-in to ¼-in, flat surface; (9) broken stone, 3-in; (10) concrete base, troweled surface, oiled with heavy flux oil; (11) sand, surface smooth; (12) clay, oiled with heavy flux oil.

"The first set of tests was made when the specimens were 1 month old. A frame made of a piece of ½-in round steel bent to surround the specimen was fastened to the pulling chain, which in turn was linked to a spring dynamometer. Force was applied by means of a light steel rail used as a long lever. Two men at the end of the lever were able to apply a constantly increasing force with great steadiness. The movements of the slab were read by means of a Berry strain gauge, and in this way the movements corresponding to known loads were obtained.

Table III.—Frictional Resistance of Concrete on Various Subbases

NOTE. Bases were somewhat damp but very firm. Weight of specimen, 870 lb.

Kind of Base	Movement	Force	Coefficient	Movement	Force	Coefficient	Movement	Force	Coefficient
Level clay	0.001	480	0.55	0.01	1130	1.30	0.05	1800	2.07
Uneven clay	0.001	500	0.57	0.01	1120	1.29	0.05	1800	2.07
Loam	0.001	300	0.34	0.01	1030	1.18	0.05	1800	2.07
Level sand	0.001	600	0.69	0.01	1080	1.24	0.05	1200	1.38
¾-in gravel	0.001	450	0.52	0.01	960	1.10	0.05	1100	1.26
¾-in broken stone	0.001	380	0.44	0.01	800	0.92	0.05	950	1.09
3-in broken stone	0.001	1060	1.84	0.01	1550	1.78	0.05	1900	2.18

"These results very clearly show that the friction varies considerably in the subbase, depending upon its character. The indications are that the friction can be greatly decreased if proper care is given to the preparation of the subbase. Every ridge or depression that is in the subbase surface before concrete is deposited, furnishes an additional grip for the concrete, thereby tending to elastically deform a larger amount of base material, and thus offering greater resistance to the sliding of the concrete.

"The formation of transverse cracks in concrete bases can readily be ascribed to direct tension due to frictional resistance at a time when the concrete is contracting, whether this is caused by decrease in temperature or by drying out of the moisture. The test results show that the coefficient of friction can readily vary from almost 0 to something over 2 or more, depending upon the movement of the concrete and the character of the subbase. The distance between transverse cracks is dependent upon the coefficient of friction, and the total force of friction must extend over this distance. Calling the coefficient of friction f, the distance between cracks d, the weight of the pavement per square foot w, we may write the equation: fwd = tensile strength of concrete per foot of width. Assuming the tensile strength of concrete to equal 200 lb per sq in, the pavement to be 6 in in thickness, the weight of 1 cu ft of concrete to be 150 lb, and the coefficient of friction to equal 0.5, this equation reduces to: $0.5 \times 75 \times D = 72$ sq in $\times 200$, or $D = 370$ ft. If the coefficient of friction equals 2, the distance between the cracks equals 90 ft."

10. Specifications for Aggregates

Fine and Coarse Aggregates. Report of Com. III, 1914 Nat. Conf. Concrete Road Building.

"**Fine Aggregates.** QUALITY. Fine aggregate shall consist of sand or screenings from hard, durable gravel, granite, trap, or other hard rock. It shall be clean, coarse, hard, free from dust, loam, vegetable, or other deleterious matter. Fine aggregate containing frost or lumps of frozen materials shall not be used.

"SAMPLES FOR TEST. Average samples of fine aggregate weighing not less than 10 lb shall be taken from the bank or pile and tested, before the acceptance of the material, for fineness and for tensile strength in mortar. Individual average samples shall be taken from each bank to be used, and new samples taken in case of a change in the character of any one bank. Receptacles for shipment to laboratory shall be such as to retain the natural moisture in the sand.

"FINENESS. The size of the fine aggregate shall be such that the grains pass when dry a screen having ¼-in openings. In the field a ⅜-in mesh or, in some cases, a ½-in mesh screen may be used for this separation. Not more than 10% of the grains below the ¼-in size shall pass a sieve having 50 meshes to the lin in, and not more more than 2% shall pass a screen having 100 meshes to the lin in. See (39) and (50d).

"TENSILE STRENGTH OF MORTAR. Mortars composed of 1 part Portland cement and 3 parts fine aggregate, by weight, when made in briquettes shall show a tensile strength at least equal to the strength of 1 : 3 mortar of the same consistency, made at the same time, and with the same cement and standard Ottawa sand. The sand shall not be dried before being made into briquettes, since this sometimes improves its quality, but correction shall be made for moisture when weighing the materials. Tensile tests may be made at ages of 72 hr, 7 days, and 28 days. At early periods the strength need not attain the full ratio of 100% to standard sand mortar, provided this is attained at a later period. In no case, however, shall sand be accepted for pavement work whose strength in 1 : 3 mortar at the age of 72 hr is not at least 80% of the strength of the standard sand mortar.

"SCREENING. If the sand does not fulfill the above requirements for fineness, it shall be washed or else screened when dry over a 10-mesh sieve placed at such an angle as to remove the particles finer than a 50-mesh sieve.

"WASHING. Fine particles may be removed by washing with a large volume of water in a box provided in the bottom with perforated pipes and arranged for the silt and water to flow off thru a trough from the top of the box and the sand to be drawn out from below.

"**Coarse Aggregate.** QUALITY. The coarse aggregate shall consist of clean, hard, durable granite, trap, conglomerate, gravel, or other hard rock, free from dust, loam, vegetable or other deleterious matter. In no case shall coarse aggregate be used which contains frost or lumps of frozen material. Coarse aggregate containing soft

particles shall be rejected. Coarse aggregate shall not contain a large proportion of flat or elongated particles.

"FINENESS. For one-course pavements, the size of the coarse aggregate shall be such as to pass an inclined or rotary screen having 1½-in circular openings and be retained on a similar screen having ⅜-in openings. For two-course pavements, the size of the coarse aggregate for the bottom course shall be such as to pass an inclined or rotary screen having 2-in openings and be retained on a similar screen having ⅜-in openings. For the wearing course in a two-course pavement, the coarse aggregate shall be of a size that will pass an inclined or rotary screen having ¾-in circular openings and be retained on a similar screen having ¼-in openings. This assumes a perfect bond between the first and second courses.

"Natural Mixed or Crushed Aggregates shall not be used as they come from the bank or crusher, but shall be screened and remixed in the proper proportions." See (20b) and (24d).

Am. Concrete Inst. and Am. Soc. Mun. Imp. Specifications for Fine and Coarse Aggregates are given in Art. 17.

Sand for Fine Aggregate for Cement-Concrete Base. Adopted by First Conference, 1917, State Highway Testing Engineers and Chemists.

"The sand shall consist of clean, hard, durable, uncoated particles, preferably silliceous, free from lumps of clay and all organic matter.

"Grading. It shall be well graded from coarse to fine and, when tested by means of laboratory screens and sieves, shall meet the following requirements:

Passing ¼-in screen	....	100%,
Passing 20-mesh and retained on 50-mesh sieve	.... % to	...%,
* Passing 50-mesh sieve	.... not more than	...%,

Not more than .....% by weight shall be removed by the elutriation test.

"Mortar Strength Test. When the sand is mixed with Portland cement in the proportion of 1 part of cement to 3 parts of sand, by weight, according to standard methods of making 1 : 3 mortar briquets, the resulting mortar at the age of 7 and 28 days shall have a tensile strength of at least....** percent of that developed in the same time by mortar of the same proportions and consistency, made of the same cement and Ottawa sand.

"Preliminary acceptance samples shall be subjected to both 7 and 28-day tests, and acceptance based thereupon. Samples tested during the progress of the work will be accepted on the basis of the 7-day test."

Sand for Fine Aggregate for Cement-Concrete Wearing Course. Same as above except for GRADING, the requirements for which are as follows:

"Grading. It shall be well graded from coarse to fine and, when tested by means of laboratory screens and sieves, shall meet the following requirements:

Passing ¼-in screen	....	100%,
Passing 20-mesh and retained on 50-mesh sieve	.... % to	...%,
†Total passing 50-mesh sieve	.... not more than	...%,
‡Passing 100-mesh sieve	.... not more than	...%,

Not more than ...% by weight shall be removed by the elutriation test."

NOTE: It is also recommended that the strength ratio, in the mortar strength test, be 100% instead of a minimum of 70% as in the previous specification.

Combinations of Dustless Screenings and Sand for Fine Aggregate for Cement-Concrete Wearing Course. Note: Same as for SAND FOR WEARING COURSE except as follows:

"The fine aggregate may be composed of a combination of dustless screenings and sand, but shall contain not more than ....¶ percent, by volume, of dustless screenings The dustless screenings shall consist of material obtained by crushing hard, durable

* "It is recommended that the amount passing the 50-mesh sieve be limited to 30%, or less, if practicable.

** "It is recommended that the minimum strength ratio for this purpose be 70% or greater, if possible under existing conditions; and that where sands giving a 70% strength ratio are not available, the proportion of cement be increased so as to give that percentage."

† "It is recommended that 25% be specified as the amount permitted to pass a 50-mesh sieve and in localities where practicable, that a smaller figure be used.

‡ "It is recommended that 5% be specified for material passing a 100-mesh sieve."

¶ The figure 50 is recommended.

rock or gravel, all of which when dry shall pass a revolving screen having circular openings ⅜-in in diameter. They shall be free from lumps or crusts of hardened material. The sand shall consist of clean, hard, durable, uncoated particles, preferably siliceous, well graded from coarse to fine, and free from lumps of clay and all organic matter.

"**Physical Properties of Dustless Screenings.** If the dustless screenings are produced from rock, the rock shall meet the following requirement:

Percent of wear.......................... not more than ...%,
or French coefficient.......................... not less than ......

"**Grading of Dustless Screenings.** The dustless screenings shall be well graded from coarse to fine, and, when tested by means of laboratory screens and sieves, shall meet the following requirements:

Passing ¼-in screen.......................... not less than ...%,
Passing 20-mesh and retained on 50-mesh sieve.......... % to ...%,
Passing 100-mesh sieve...................... not more than 5%."

Stone or Gravel Screenings for Fine Aggregate for Cement-Concrete Base. Adopted by the First Conference, 1917, State Highway Testing Engineers and Chemists.

"The screenings shall consist of material obtained by crushing hard, durable rock or gravel, all of which shall pass a revolving screen having circular openings ⅜ in in diameter. They shall be free from lumps of clay and at the time of use from lumps or crusts of hardened material.

"**Physical Properties.** If the screenings are produced from rock, the rock shall meet the following requirement:

Percent of wear.......................... not more than ....%,
or French coefficient.......................... not less than ......

"**Grading.** The screenings shall be well graded from coarse to fine and, when tested by means of laboratory screens and sieves, shall meet the following requirements:

Passing ¼-in screen.......................... not less than ...%,
Passing 20-mesh and retained on 50-mesh sieve.......... % to ...%,
Passing 100-mesh sieve...................... not more than ...%.

"**Mortar Strength Tests.** When that portion of the screenings, which passes a ¼-in laboratory screen, is mixed with Portland cement in the proportions of 1 part of cement to 3 parts of screenings, by weight, according to standard methods of making 1 : 3 mortar briquets, the resulting mortar at the age of 7 and 28 days shall have tensile strength of at least ...* percent of the strength developed in the same time by mortar of the same proportions made of the same cement and Ottawa sand.

"Preliminary acceptance samples shall be subjected to both 7 and 28-day tests and acceptance based thereupon. Samples tested during the progress of the work will be accepted on the basis of the 7-day test."

Broken Stone or Gravel for Coarse Aggregate for Cement-Concrete Base. Adopted by First Conference, 1917, State Highway Testing Engineers and Chemists.

"The broken stone or gravel aggregate shall consist of clean, hard, tough, durable rock. It shall contain no vegetable or other deleterious matter, and shall be free from soft, thin, elongated or laminated pieces.

"**Grading.** The broken stone or gravel shall be graded from coarse to fine and when tested by means of laboratory screens shall meet the following requirements:

Passing ... in screen.................................. 100%,
Passing ... in screen...................... not more than ...%."

Broken Stone for Coarse Aggregate for Cement-Concrete Wearing Course. Same as for BROKEN STONE FOR BASE, except as follows:

"**Physical Properties.** The stone shall meet the following requirements:

Percent of wear.......................... not more than ...%,
or French coefficient...................... not less than .....

"**Grading.** The broken stone, when tested by means of laboratory screens, shall meet the following requirements:

Passing ... in screen.................................. 100%,
Passing ... in screen and retained on ... in screen...... % to ...%,
Passing ... in screen...................... not more than ...%."

*It is recommended that the minimum strength ratio be 90% for this purpose.

CONSTRUCTION

11. Equipment and Construction Organizations

The Equipment necessary for concrete road construction will depend largely on local conditions. For an admirably comprehensive list of the field and office appliances used in constructing by force account twelve miles of concrete roadway in one working season see (26b).

Examples of Concreting Gang Organization (50r) for road work are given in the following examples.

" **Pennsylvania. Easton-Bethlehem Model Road.** The best results were obtained with a gang organization as follows:

Gang	Cost per Day
1 foreman at $3	$3.00
1 mixer operator at $3	3.00
1 fireman at $2.50	2.50
2 templet men at $2	4.00
3 men spreading at $2	6.00
2 men floating at $2	4.00
1 man finishing at $2	2.00
2 men on forms at $2	4.00
1 man changing chute at $2	2.00
2 men handling cement at $1.75	3.50
7 men on wheelbarrows at $1.75	12.25
7 men shoveling at $1.75	12.25
1 utility man at $1.75	1.75
1 waterboy at $1.50	1.50
32 men in total gang,	$61.75

Laying a slab 7 in thick and holding the material in the drum for a 90-sec mix, this gang averaged 525 sq yd per day at a cost of approximately 11.7 cents per square yard. A No. 16 Koehring paving mixer, with boom and bucket delivery, was used.

" **Illinois.** The data given are based on experience on 25 to 30 jobs of state aid road work representing approximately 500 000 sq yd of pavement. Assuming excavation complete and all material delivered on the work and that the subgrade is in average condition, the following crew is considered to be most efficient under average conditions on work similar to state aid road work in Illinois.

General	Number
Superintendent	1
Foreman	1
Front End of Mixer	
Wheeling sand	2
Wheeling stone	4
Extra shovelers	2
Bundling cement sacks	1
Handling cement	2
Trimming subgrade	1 or 2
Rear End of Mixer	
Shovelers	3 or 4
Finisher	1
Curing concrete	2
On Mixer	
Engineer	1
Fireman	1
Forms, Setters	2
Water, Pumpman	1
Miscellaneous	
Watchman	1
Waterboy	1
Total	27 or 29

The gang is for a 2-bag batch mixer, and with this machine its average daily output of 18 ft wide and 7 in thick pavement is about 800 sq yd, working day 9 hr, mixing time per batch, 35 sec. The average cost of mixing and placing concrete and of setting forms and joints is 10 to 12 cents per sq yd.

" Wisconsin, Milwaukee County Roads. An efficient gang organization for conditions prevailing in Milwaukee County has been found to be about as follows:

Gang	Cost per Day
1 foreman at $5	$ 5.00
1 timekeeper at $5	5.00
1 engineer at $5	5.00
1 fireman at $2.50	2.50
1 pumpman at $2.50	2.50
1 form setter at $2.50	2.50
1 finisher at $3	3.00
2 strike-off men at $2.50	5.00
2 puddlers at $2.50	5.00
2 cement handlers at $2.50	5.00
1 boy bundling sacks at $1.50	1.50
1 waterboy at $1	1.00
6 sand laborers at $2	12.00
12 stone laborers at $2	24.00
1 man removing forms at $2	2.00
2 men covering concrete at $2	4.00
1 man sprinkling at $2	2.00
1 man trimming subgrade at $2	2.00
38 men total	$89.00

"The particular road on which this gang worked contained 17 280 sq yd, was 18 ft wide and averaged 7 in in thickness. The mix was 1 : 2 : 3½, 2 bags of cement being used to a batch, and 11 cu ft of aggregate. Protected joints were placed every 50 ft. During this period, the maximum output for one day was 1000 sq yd and the minimum 264 sq yd. The average output was 665 sq yd per day or 332½ lin ft per day. The actual labor cost for mixing and placing was $0.1396 per sq yd, which included labor incurred in supplying water covering and sprinkling concrete and also a watchman during the construction period. The cost to the contractor for lost time, moving plant to and from the job, the laying of pipe, etc, amounted to $0.0201, giving a total cost per sq yd for labor of $0.1597."

12. Mixed Cement-Concrete Pavements

One-Course Work is simply the construction of the entire concrete layer from the subgrade up to the finished surface continuously and in consecutive areas of pavement. The placed concrete, such as the Hassam pavement, before referred to, constructed as one-course work because the grouting is done entirely from the top of the aggregate when rolled, even tho the aggregate itself may be laid in two or more layers. With mixed concrete, the deposition of the entire concrete layer in one thickness would be one-course work. One-course work seems to be growing somewhat in favor, altho the difficulties of properly tamping and compacting a layer of the usual thickness of one-course work are apparently greater, than in the case of the two-course work where the layers are of less thickness.

Two-Course Work consists in placing the concrete pavement in two layers, generally known as the bottom course and the top course respectively. Frequently the bottom layer is of coarser aggregate than the top layer and it often is of a leaner mixture of cement for the sake of economy. In these respects, it is similar to the ordinary side walk or foot-way construction when concrete is used. The difficulties with two-course work seem to be

mainly those of securing a proper bond between the lower and the upper courses. Generally in two-course work, especially where different materials and proportions are used in the two courses, the bottom course is laid for some distance ahead of the upper course, and then the upper course is run. A certain amount of setting in the lower course unavoidably takes place before the placing of the upper course begins, and a seam frequently appears to exist between the two courses which results in weakening the strength of the upper thickness, just as a 2-in plank laid on another will not support as much of a load with the same deflection as one plank 4 in in thickness. Further with a great deal of two-course work, it has been noticed that there is a tendency at the expansion joints for the upper course of one of the areas to separate from its lower course and override the upper course of the adjoining area, especially where expansive movement of the concrete is considerable. This is of common notice in many side walk pavements of concrete. It is possible with two-course work to secure a denser wearing surface of the pavement with no greater expenditure for cement than can be had with one-course work, and, especially where the concrete pavement is to be directly subjected to traffic, a high degree of density in the wearing surface is desirable. On the other hand, with equal proportions of cement, the one-course work is probably stronger under heavy loads, and over soil or other foundations of weak supporting power than the two-course work, and this is an important consideration where the total thickness of the concrete layer is near the minimum allowable.

The Report of Com. XI, 1914 Nat. Conf. Concrete Road Building included the following recommendations:

Depositing Concrete. "Just before placing concrete, the subgrade should be well sprinkled so that it will not absorb moisture from the concrete, and should be checked by the engineer or inspector to make sure that the required thickness of concrete can be placed. Probably the most satisfactory method of depositing the mixed concrete in position on the subgrade is by means of a bottom dump bucket running on a swinging boom from the mixer. The boom can be swung over any position on the subgrade, and the bucket can be run out and dumped at any point along the boom. Such equipment does not depend for economic operation upon consistency, and the concrete can be easily handled and deposited at any place on the subgrade, necessitating but little handling with shovels. When concrete is placed by means of the open trough, care must be exercised to see that it is not mixed too wet as this method of distribution depends for economic operation very much upon the consistency of the concrete. An open trough is necessarily much shorter than a boom and is more limited in action, which requires that the mixer be moved ahead more often, also that more of the concrete after being deposited on the subgrade be handled with shovels. When a batch mixer, not having a boom and bucket or open trough, is used, the concrete should be handled in wheelbarrows or hand carts wheeled on suitable runways. Placing concrete by means of horse carts should not be permitted as they cut up the subgrade badly, and to get the concrete into final position requires a maximum amount of shoveling. Whatever the method of conveying and placing, the concrete should be deposited upon the subgrade to the required depth and for the entire width of pavement in as nearly one operation as practicable so as to reduce handling to a minimum. If it is necessary to handle a large amount of material with the strike-board it will ride the concrete and thus produce a wavy, uneven surface.

"**Use of Strike-Board.** The excess of coarse material that accumulates in front of the strike-board should be uniformly distributed over the surface of the pavement and not left in narrow strips across the section, or placed along transverse expansion joints. An ordinary garden rake will be found useful in distributing the material that accumulates in front of the strike-board. When the strike-board is within 2 ft of an expansion joint, the excess material that has accumulated in front of it should be removed with a shovel and deposited on the subgrade in the next section. Special care should be taken to place good dense concrete along expansion joints, and all in-

equalities at the joints, including any small holes left after the removal of the installing device, should be filled with a mortar composed of one part cement and not more than two parts fine aggregate. The men handling the strike-board should follow closely behind those placing the concrete, for keeping up with the strike-board will materially assist those placing concrete in depositing the required amount of material. The placing of concrete should be a continuous operation, and stops should be made only at expansion joints. In case the mixer breaks down concrete should be mixed by hand to complete the section, or an expansion joint should be placed at the point of stopping work. Any concrete in excess of that needed to complete the section, when work is discontinued, should be spread out in a thin layer, not exceeding 2 in in thickness, over the subgrade in the next section and not piled up along the expansion joint. In striking off a pavement 16 ft or less in width, where the concrete has been properly placed, two men should be able to handle the strike-board, but for wider pavements the services of a third man will be required to assist in pulling the board forward by means of a drag line fastened at its center. The strike-board should always be worked forward about perpendicular to the axis of the roadway, and as it is moved ahead should be sawed back and forth across the road. To produce the desired effect will require that the strike-board be passed over the surface of the concrete two or more times. Tho it will be necessary for the workmen to get into the concrete some after it is deposited on the sub-base, it is desirable that all unnecessary walking in and wading thru the concrete be avoided, and under no circumstances should any workmen step upon the concrete after it is first struck off." See (50j).

"**Description of Strike-Board.** The strike-board should be cut to conform to the crown of the finished surface of the pavement and should be of sufficient strength and stiffness to show no deflection at the center when supported at the ends, nor a material bowing out of alignment when in use. It should be about 2 ft longer than the width of the road, protected on the bottom edge with a metal facing and provided at each end with suitable handles. For roads up to 12 ft in width two 2 by 6-in planks, dressed on one side and both edges, spiked together, make a good strike-board, and for roads 12 to 20 ft in width two 3 by 8-in or a 2 by 10-in and a 3 by 10-in, spiked together, will be found satisfactory. Two planks, well spiked together, make a better strike-board and one less likely to warp out of shape than a single piece. The strike-board should not be so heavy that it cannot be easily handled by two men, and to reduce weight and increase stiffness, it is advisable for work over 20 ft in width to use a strike-board composed of boards 2 or 3 in thick, stiffened by trussing, rather than obtain the required stiffness by the use of heavier timbers."

The Use of a Belt in Surfacing Concrete Pavements. (19a) "Two belts were secured; one 3-ply 8-in canvas belt and one 5-ply 10-in belt, both having a composition rubber covering. The concrete was mixed at such consistency that when deposited in a pile it would tend to flatten but would not run at the edges. The concrete was struck off in the usual manner and after the surplus water disappeared from the surface of the concrete, the 8-in belt was dragged back and forth over the pavement with practically the same motion as used for the strike-board. Just prior to the concrete taking its initial set the pavement is gone over a second time with the belt. This second floating grinds down all the ridges left after the first floating. The second floating leaves a gritty, granular mortar surface entirely free from ridges, flat spots or pockets. It was found that better results could be secured by the use of a 10-in belt for the second floating because of its greater weight, but if the heavier belt was used for the first floating, it had a tendency to flatten the crown in the soft concrete and to dig into the surface. In Kane County the contractor is placing from 600 to 800 sq yd of 18-ft concrete pavement per day and has no finisher on the pay roll. The strike-board men handle the belt and do the edging. Where armored joints are used it is necessary to do a small amount of hand floating around the joint, but this is done by the men who place the joints. This construction feature appeals to the contractor as it saves him money and the worry of keeping a good finisher on the job; and it appeals to the engineer because of the superior surface and the fact that its operation is nearly foolproof."

Rolling the Concrete after its placing has been referred to. Theoretically such rolling is desirable for securing the proper compaction of the mass, for securing greater homogeneity in and evenness of surface, and for securing in the surface such disposition of the larger particles of aggregate

such as broken stone, as will result in their closely interlocking by their angles and their presentation to wear of a flat face rather than of an edge or point. Practical difficulties often exist in the way of rolling the wet mixture without interfering disadvantageously with the setting process. Rolling has, however, been done on mixed concrete with much success. For a description of means and methods see (16), and VIBRATED CONCRETE, Art. 17.

Curing the concrete properly is a most important detail of construction. Some means must be had for retaining sufficient moisture in the mass and adjacent to it sufficient to prevent, as far as practicable, while the setting is taking place, the formation of cracks or a loss of strength in the concrete. One fairly satisfactory method has been to allow the finished concrete to harden superficially, enough to prevent its being damaged by the process, and then to cover it with several inches of sand or earth, which latter is thereafter kept constantly wet by being sprinkled. Another means has been to build low earth dams along and across the concrete roadway impounding a few inches of water within the dams and over the concrete. Wet canvas or straw coverings have also been used. See (32) and (50i).

18. Expansion-Contraction Joints

In uncarpeted concrete pavements, it may be necessary to provide opportunities in the form of prepared joints whereby the movement of the concrete slab thru expansion and contraction under varying climatic conditions can be taken up with the minimum of injury to the slab itself. Such joints are ordinarily termed expansion joints, but as a matter of fact, the better name for them would be contraction joints. It has been sufficiently demonstrated that the movement in the concrete slab due to varying degrees of moistness of the slab is far greater and appreciable than that due to varying degrees of temperature of the slab. Changes in temperature produce some movement in the slab but the movement so produced is so slight that it is almost negligible, except in cases of the longest slabs. On the other hand, the movement in the slab occurring between the condition when it is most nearly saturated with water and the condition when it is freest from water is relatively large, and it is this movement for which provision must be made in order to protect the slab itself. Concrete being laid in a saturated condition must at that period occupy its greatest area of the road. As it sets and dries out, it contracts and cracks tend to form.

The Minor Superficial Cracks thus formed are frequently termed hair cracks, and generally affect only the surface. They are of almost negligible importance, outside of considerations of appearance, in connection with the use of concrete for pavements. Their reduction to the minimum is dependent upon the composition, workmanship, and the ultimate density and strength of the concrete itself. In the case of large slabs, the shrinking movement due to drying may reach such proportions as to produce separation in the slab itself between portions of the slab unable, for one reason or another, to conform further to the shrinking movement. See (28b).

The Difficulties of the Construction of Joints come mainly from the increase in cost in providing them, and the obstacles at present existing in the way of securing a proper joint filler under any particular condition. Some form of bituminous filler is the usual material used and various advantages are claimed for the different ones on the market. Characteristerics desirable in the bituminous filler are sufficient adhesion to prevent its separation from the concrete adjoining, sufficient cohesion to prevent separation in the bituminous filler itself, sufficient resistance to heat to prevent

its flowing out of the joint in the hottest weather, sufficient resiliency to prevent its being broken out of the joint by the shocks of traffic in the coldest weather, and such durability of these qualities as will give a reasonable and satisfactory life under use.

The Provision of Expansion Joints in an uncarpeted concrete pavement, or in a concrete pavement under which a carpet of less than ½ in thickness is expected to be maintained is usually made. In the uncarpeted roadway, they may be made from 25 to 100 ft apart, the distance between them being dependent upon local conditions, and should extend across the roadway the full depth of the slab. In the thinly carpeted road, they may safely be at greater intervals or omitted altogether. They may be either at right angles to the axis of the road, or at a different angle. The angle of 45° with the axis of the road has been recommended, especially from the greater ease of passage over the joints, tho the length and cost of the latter is evidently increased by the adoption of this angle. On curves it is customary to make them radial. The width of the joints in any case must depend upon local conditions as well as upon the frequency determined upon. The Hassam pavement does not seem to require for its protection contraction joints to the extent required by other concrete slabs. See (54).

The Report of Com. II, 1914 Nat. Conf. Concrete Road Building (50c) contained the following conclusions:

"**The Expansion Joint Should Fulfill the Following Conditions:**

1. It should be located at the proper spacing, experience points to a distance of 25 to 30 ft when the pavement is not reinforced.
2. It should be designed of sufficient thickness and depth to withstand the traffic.
3. Metal should be hard enough to withstand abrasion but should not be brittle.
4. The expansion joint protector should be simply installed.
5. It should provide a strong bond with the road slab.
6. The filler between the protectors should be plastic to permit expansion and contraction, and keep out grit and water. Both plastic asphalt and tar felt paper are used with satisfaction.
7. The protector should be as inexpensive as consistent with good service. The subject of expansion joints for concrete pavements resolves itself into three divisions, namely, Location, Type and Maintenance.

"**Maintenance of Joints.** Expansion joints should be kept filled to the level of the pavement surface so that there will not result an impact when wheels cross the joint. If the joint is not kept filled, grit will accumulate and in time the joint will be filled with non-elastic material. Even a joint which has been kept filled will in time become jammed with grit."

In this connection, the report of Com. I (50a) on the "Contraction and Expansion of Concrete Roads" is very full and extremely valuable for study. See (30) and (69a).

Pennsylvania Practice (63). "Joints, ¼ in wide, are provided at intervals of from 36 to 40 ft. These are filled with a prepared bituminous material, ¼ in thick and 9 in wide, placed in accordance with the standard practice. The concrete on either side of the joint is finished with a split float, which gives a surface of even height on both sides of the joint and overcomes to a great extent the so prevalent rough riding joints. The edges of the joints are then rounded with a $^3/_{16}$-in edger to prevent the spalling or breaking of the edges. The bituminous joint material is trimmed off about 1 in above the finished surface, which permits traffic to beat down the projecting filler, thus forming a protection to the edges. The sides of the slab are then rounded with a ¼-in edging tool, which not only adds to the appearance of the work, but serves also to protect the sides and prevents chipping by traffic turning on and off the road."

Omission of Joints. The tendency in practice seems to be toward the omission of prepared joints and the reliance upon other means, such as reducing the movements and strains in the slab by securing greater uniformity and density, for meeting the demands of conditions causing contraction and expansion. The California practice has been to omit the provision of expansion joints, see (31). See also (21), (50b) and (50c).

14. Reinforced Cement-Concrete Pavements

The effort has been made to increase the strength of concrete slabs for road pavements, and also their power of resistance to expansion and contraction strains by the insertion of metal reinforcement in the body of the concrete. The usual method of so doing is to have the reinforcement in the shape of wire netting, or some of the special forms like the expanded metal meshing, and to place this reinforcement between the bottom and top courses of the pavement. Where used with one-course work, such as the Hassam pavement, a layer of stone is usually spread and rolled, then the netting placed on this surface and the final layer of stone spread over the netting and rolled. Some additional strength is undoubtedly given the concrete slab by the presence of the reinforcement. Its resistance to deflection under a load is relatively only slightly increased because of the tendency of the reinforcement to divide the slab with a seam into two layers, between which resistance to shear may be low, while the increase in bending moment can only be figured by the additional strength given from the reinforcement to the beam having the depth only from the upper surface to the reinforcement, instead of the whole depth of the concrete slab. The reinforcement undoubtedly adds considerable to the tensile strength of the slab and should permit the location of the contraction joints considerably further apart than in the cases of unreinforced slabs. See (62).

The Report of Com. V, 1914 Nat. Conf. Concrete Road Building (50f) included the following conclusions:

"Since concrete has little tensile strength, it is inelastic and cracks may develop from the following causes: (1) Changes in temperature; (2) variation in the percentage of moisture in the concrete; (3) defective foundation; (4) improper drainage; (5) insufficient thickness in slab to carry the traffic; (6) faulty construction.

"It is necessary, therefore, in a pavement properly designed and constructed, to minimize the cracks resulting from the above causes by imbedding a reinforcement in the concrete which will so distribute the tensile stresses as to prevent formation of larger cracks.

1. Reinforcement for Temperature Changes. The effect of an increase of temperature is to increase the length or expand the concrete pavement and a decrease in temperature is to decrease or shorten the pavement. In the latter case, assuming that there is no reinforcement, cracks will form at more or less regular intervals. These cracks will occur at right angles to the direction of the line of the roadway at intervals of 25 or 50 ft. Since concrete and steel have practically the same coefficient of expansion, namely, 0.0000055, the two materials will expand or contract equally under temperature changes, but the presence of the steel prevents the entire effect from being localized at one point and distributes the stress over a considerable space, thereby preventing any large cracks. The common practice is to provide joints in concrete pavements that are not reinforced at intervals of from 25 to 50 ft. Thru the use of reinforcement the spacing of these joints may be very materially increased and it is possible to so reinforce a concrete pavement as to render joints either wholly unnecessary or at extremely long intervals. By properly reinforcing the roadway, the thickness may within limits be decreased thereby increasing the serviceability of the roadway and decreasing the cost.

2. Variation in the Percentage of Moisture in the Concrete. Experiments seem to indicate that concrete expands when thoroly wetted and shrinks when thoroly dried out, and that the change of length due to this cause is about 0.005 per unit of length. Experiments seem also to show that expansion and contraction, due to the variable content of moisture which results from extreme wet or dry weather, produces cracks in the concrete, unless the pavement is sufficiently reinforced to distribute these stresses in the manner described under reinforcement for temperature changes. Further proof is desirable, however, before this fact is accepted, and further experiments are needed to show the effect of density and mass on the percent of moisture in concrete. It seems likely that a very dense mass of concrete of some thickness will only be superficially affected and the mass will not be materially affected.

3. Defective Foundation. Concrete pavements laid on a subgrade which contains fills or other soft places which are liable to settle, thus leaving the concrete pavement without proper support, will result in cracks unless the pavement be sufficiently reinforced to distribute the load over a larger area, thereby bridging over these soft places where there has been settlement in the subgrade.

4. Insufficient Thickness of Slab to Carry the Traffic. Where the traffic on the road is very heavy it frequently happens that the concrete unreinforced is insufficient in thickness to support this load, especially if the subgrade is not of suitable character, and both longitudinal and transverse cracks are the result. Settlement in the foundation under heavy traffic will produce objectionable longitudinal cracks. The introduction of reinforcement in the pavement distributes the load and thereby prevents the formation of these cracks.

5. Faulty Construction. These same cracks and imperfections appear when faulty construction occurs, which is generally the result of improper design or supervision, or both.

"The percentage of reinforcement required in a concrete roadway will depend on the nature of the traffic, the conditions in the subgrade and the range of temperature and the variation in percentage of moisture. Your Committee, therefore, is unable to prescribe the exact amount of reinforcement required since it will vary with each road. In general, however, the reinforcement should be about 0.1% per foot of width."

The Report of Com. IX, 1916 Nat. Conf. Concrete Road Building (50f) opened with the following statements:

"Your Committee, in considering the reinforcement of concrete roads, find little data available and no well defined practice. Many highway engineers use the recommendations of the 1914 Nat. Conf. Concrete Road Building and the standard specifications of the Am. Concrete Inst.. It is only recently that reinforcement has been used to any great extent, and the interval is too short for the accumulation of the data necessary to standardize practice."

It included among many others of interest in this connection, the following paragraphs: "While not directly within its province, your committee believes that the number and the character of the joints have a vital bearing on the life of a concrete road. It further believes that joints may be greatly decreased or practically eliminated by proper reinforcement. All joints are objectionable and many are a menace to the life of the concrete road."

The Committee recommended that "all concrete roads shall be reinforced", but the Conference itself in its "Recommended Practice" simply stated on this point that "The use of reinforcement in concrete pavements is increasing."

Rods Hold Settling Concrete Pavement Together (19b). "Twelfth St., Cook County, Ill., east of Hillside, presents a striking example of the settlement of a rigid pavement laid on a yielding subgrade. At this point the road extends thru a slough for 600 ft, and tho the maximum settlement at the time the last levels were taken was 1.74 ft, it is still in good condition. While a considerable number of small transverse cracks have developed, no longitudinal or diagonal cracks have appeared. The longitudinal reinforcement has kept the cracks from becoming large, and if these are given ordinary maintenance, the utility of the road will not be seriously impaired.

Table IV.—Settlement of Center of Road in Inches

Station	Aug. 18, 1915 After 43 Days	Mar. 9, 1916 After 8 Months	Nov. 17, 1916 After 16 Months
155	0.02	0.00	0.01
156	0.00	0.00	0.01
157	0.24	0.58	0.90
158	0.32	0.73	1.09
159	0.37	0.79	1.11
160	0.60	1.29	1.74
161	0.49	1.14	1.56
161 + 38	0.08	0.49	0.81

Specification for Steel Reinforcing Rods. Adopted by First Conference, 1917, State Highway Testing Engineers and Chemists.

"Rods shall be (insert form selected)* and (insert method of manufacture desired)** and shall conform to the following chemical and physical requirements. Twisted bars shall be twisted with one complete twist in a length not over 12 times the thickness of the bar.

"**Chemical Properties.***** Rods shall meet the following chemical requirements:

Phosphorus	Bessemer	not more than x %
	Open-hearth	not more than x %

"**Physical Properties.** Rods shall meet the following requirements for physical properties:

Tension Tests:	
Tensile strength	not less than x lb per sq in
Yield point	not less than x lb per sq in
Elongation in 8 in	not less than x %
Cold bend test without cracking:	
Thickness or diameter ¾ in	x°.
Thickness or diameter ¾ in or over	x°.

"**Modifications in Elongation.** For plain and deformed bars over ¾ in in thickness or diameter, a deduction of 1 from the percentages of elongation specified in the foregoing table shall be made for each increase of 1/8 in in the thickness or diameter above ¾ in. For plain and deformed bars under 7/16 in in thickness or diameter, a deduction of 1 from the percentage of elongation specified in the foregoing table shall be made for each decrease of 1/16 in in thickness or diameter below 7/16 in.

"**Weight.** The weight of any lot of bars shall not vary more than 5% from the theoretical weight of that lot.

"**Storage.** Steel rods shall be so stored as to prevent the formation of rust scales and when used on the work they shall be free from dust, dirt, loose rust, paint, oil or grease."

15. Specifications for Mixed Cement-Concrete Pavements

Fundamental Principles Adopted by the 1916 Nat. Conf. Concrete Road Building (50a), as representing good practice in the construction of concrete pavements:

"**Brief Summary of Fundamental Principles.** The salient features of the practice recommended by the Conference are:

1. Drainage of the road-bed is vital.
2. Subgrade must be of uniform density and should be compacted.
3. Aggregates must be clean, hard and tough.
4. Fine aggregate, sand, should be coarse and well graded.
5. A rich mixture must be used.
6. Materials must be accurately proportioned.
7. Mixing must be most thoro.
8. Sloppy concrete must not be used.
9. In general, the use of reinforcement is justifiable.
10. Inspection must be intelligent and thoro.
11. Concrete must be protected from rapid drying.
12. Pavements must not be opened to traffic too soon.

"The details of recommended practice are as follows:

"**Materials.** PORTLAND CEMENT shall meet the requirements of the Standard Specifications for Portland Cement of the Am. Soc. Test. Mat. and tests should be made in accordance with the methods of testing outlined by the Am. Soc. C. E. See (69c).

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*Plain, deformed, hot or cold twisted, as may be desired.

**Rolled from new billets made by Bessemer or open-hearth process or rolled from standard section Tee rails, as may be specified.

***To be applied only to rods rolled from billets.

x The values given in American Society for Testing Materials Standards, 1916, Serial Designation A15–14, for the particular kind of material desired, are recommended for insertion in this table.

"AGGREGATES. The selection of proper aggregates for concrete pavement construction is of utmost importance. Clean, hard, well graded materials are absolutely essential to success. For this reason samples of the materials proposed for use should be submitted to the engineer for approval before orders are placed. These samples should be carefully inspected; and, if possible, laboratory tests be made upon them to determine their suitability. If laboratory tests on shipments cannot be made, field tests can be used to furnish a general indication of quality. The different aggregates should be kept clean, and separate until used. Aggregates to be used in the wearing course of two-course pavements should never be placed on the subgrade but on planks, unless some other means is provided to keep them free from dirt. If aggregates are placed directly on the subgrade, care should be used by the shovelers to avoid getting clay or earth, shoveled from the subgrade, into the mix. Aggregates should not only be clean when they are delivered on the job, but clean when placed in the mixer.

"WATER SUPPLY is a most important factor and is frequently overlooked by the engineer and contractor. A large supply of water is necessary for (1) sprinkling the subgrade; (2) mixing the concrete; and (3) keeping the concrete moist during early stages of hardening. For the last purpose 25 to 30 gal per sq yd of pavement will be required during the summer months. Unless sprinkling is thoro the wearing qualities of the pavement will not be all they should be.

"The use of REINFORCEMENT in concrete pavements is increasing. A coating of light rust will not be detrimental to satisfactory results but care should be exercised that no excessive rust, paint or other coatings are present to interfere with proper bond. Care should also be exercised to see that the reinforcement is so stored prior to use, that it is not coated with mud or clay when placed in the pavement. Reinforcement left on a job when the contract is not complete at the end of the season should be collected and stored so that it will be protected from the elements. Occasionally tensile and bending tests should be made to see that the requirements of the specifications are fulfilled.

"JOINT FILLER should preferably be of a single thickness. Transverse joint filler should be cut to the crown of the pavement by the manufacturer, when metal plates are used. A type of joint filler which will iron out readily under traffic is preferable for use in unprotected joints. A joint filler which will not bend easily when concrete is deposited against it is to be preferred.

"METAL JOINT-PROTECTION PLATES should be properly bundled and wired by the manufacturer so that they will arrive on the work in good condition, free from warp. Protection plates up to 20 ft shall be shipped in single lengths. The exact length required should be provided so that the contractor will not find it necessary to cut plates. In cutting plates for length, spacing between eccentrics on the installation bar should be considered to avoid interference with anchorage lugs on plates. Particular care should be used by the manufacturer in crowning the installing bar, to avoid the necessity of duplication of work by the contractor.

"The Drainage of the road-bed is of vital importance. If the subgrade is not well drained, there is danger of unequal settlement or frost action, which will cause cracks. The method of drainage to be used will depend upon local conditions. For roads, proper drainage may be secured thru lateral ditches. For streets, as well as roads, tile drains may be used. These should be laid on each side of the roadway, or may be laid on one side only, with cross-drains leading thereto at a suitable depth, depending on the width of the pavement. Drainage trenches, if placed under the subgrade, should be completed before final rolling.

"Grading. When roadways are constructed over fills, extreme care should be observed to insure the use of proper materials in layers of such thickness that the materials may be thoroly compacted so that when the fill is completed there will be a minimum of settlement. In general, fills shall be made in thin layers, the thickness depending on the character of material to be used in making the fill. The fill should be allowed to stand for as long a time as possible, to give it an opportunity to settle thoroly before the pavement is placed thereon. Deep fills should be allowed to settle thru one winter wherever such procedure is possible. Puddling will be found advantageous in compacting deep fills. Wetting and rolling shall be performed when making a fill in order to secure thoro compactness. Fills should never be made with frozen materials, nor with lumps greater than 6 in in their greatest dimension.

"Subgrade. The fundamental requirement of the subgrade is that it should be of uniform density so that it will not settle unevenly, thus causing cracks in the surface

of the pavement. No part of the work is more deserving of intelligent care and pains-taking labor than the preparation of the subgrade. The slight additional cost necessary to insure good results is abundantly justifiable. When the pavement is constructed on virgin soil, care should be taken to remove all soft spots so as to insure a uniform density; and if constructed on an old road-bed, even greater care must be taken to secure uniform density, as the subgrade is likely to be more compact in the center than at the sides. An old road-bed should be scarified, reshaped and rolled. The subgrade adjacent to the curb should be hand tamped.

"**Forms.** Metal side forms of sufficient strength to withstand the necessary hard usage are preferred. When wooden forms are used they should be of 2-in stock, at least, and capped with a 2-in angle iron, and so constructed that adjacent sections can be lapped. Forms should have a width not less than the thickness of the pavement at the sides. Particular care should be exercised to see that the top edge of forms is clean so as to avoid unevenness in the finished pavement. If forms are warped or stakes not properly placed, a poor alignment of the edge of the concrete slab will result. See (70).

"**Pavement Section.** The THICKNESS of a concrete pavement is controlled by many factors, each of which should be given consideration. In view of the increasing use of the heavy motor truck and bus, it seems unwise to build pavements with a thickness of less than 6 in at any point. In general, pavements should be thicker at the center than at the sides. Alleys with an inverted crown, and narrow one-slope roads, should have a uniform thickness. Wherever the thickness can be increased without excessive cost, to secure a flat subgrade, or one nearly flat, such increase is advisable.

"The desirable WIDTH for a single-track road is 10 ft. The desirable width of double-track roads is 18 ft. The total width of the roadway should be not less than 20 ft for single-track roads and not less than 26 ft for double-track roads.

"The CROWN of pavements should be not less than 1/100 nor more than 1/50 of the total width. Except in unusual cases, 1/100 will be considered satisfactory for alley pavements. For city streets an average crown of 1/75 will generally be found sufficient, and should not be reduced, except on grades.

"**Joints.** TRANSVERSE JOINTS should be placed across the pavement perpendicular to the center line about 50 ft apart. There seems to be a tendency to widen the distance between joints. Joints should extend entirely thru the pavement, as well as thru the curb if integral curbs are used. Joints should be constructed perpendicular to the surface of the pavement to avoid the possibility of one slab rising above the other.

"LONGITUDINAL JOINT FILLER should be staked or otherwise securely held against the curb. Joint material should also be placed around manholes, catch basins, etc.

"PROTECTED JOINTS. The tendency of present practice is toward the omission of metal protection plates for joints. It is possible that the value of metal protection plates is dependent somewhat on the character of aggregate used, and it is considered that they are more essential in street pavements than in country highways.

"PLATES for protected joints should be wired together with the joint filler in place and securely held in the installing bars. When short sections of joint filler are used they should likewise be wired together. Supports for the joint should be used when the pavement is of such width that the installing bar deflects. On wide streets every joint should be checked as to crown with sighting T's. When necessary to have joint plates in two sections, the contractor should arrange with the manufacturer to have holes drilled in the abutting ends of the plates so that the plates may be securely wired or strapped together. As the joint plates usually do not fit tight to the installing bar, a 1/4-in shim is placed under each end of the installing bar, to insure that the plates are not covered by the concrete.

"**Mixing and Placing Concrete.** The method of MEASURING materials for the concrete, including water, should be one which will insure accurate proportions of each of the ingredients at all times. It is recommended that a sack of Portland cement, containing 94 lb net, be considered as equivalent to 1 cu ft.

"The PROPORTIONS should not exceed 5 parts of fine and coarse aggregate, measured separately, to 1 part of Portland cement, and the fine aggregate should not exceed 40% of the mixture of fine and coarse aggregates.

"AGGREGATES. Bank run material shall not be used. Proportioning based on sieve analysis or by relative density tests is not practical for concrete pavements except

where laboratory direction is available. But where proper facilities are available, the above proportions should be varied as the tests warrant.

"MIXING. The ingredients should be mixed in a batch mixer of approved style, and the size of the batch should not exceed the rated capacity of the mixer. The mixing should be continued for at least 1 minute after all materials are in the mixer and before any of the concrete is discharged. The speed of the mixer should not exceed 16 rev per min; the number of revolutions per batch should not be less than 10; however, the time, and not the number of revolutions, should be the factor for determining proper mixing, in order to distribute the water thru the batch.

"CONSISTENCY. The practice is to mix concrete entirely too wet. The consistency should be such as not to require tamping, but not so wet as to cause the separation of the mortar from the aggregate in handling and placing. The strength and wearing qualities of the concrete are vitally lessened by an excess of water in mixing.

"PLACING. If the subgrade has been disturbed by teaming or from other causes, it should be brought to its former surface, and thoroly saturated with water. The concrete should be deposited rapidly to the required depth and width. The section should be completed to a transverse joint, without the use of intermediate forms or bulkheads, or a transverse joint may be placed at the point of stopping of the work. In case the mixer breaks down the concrete should be mixed by hand to complete the section. Where reinforcement is used it should be embedded in the concrete before the concrete has begun to harden; and the concrete above the reinforcement should be placed within 20 min after the placing of the concrete below. In two-course pavements the top should be placed within 20 min after the placing of the bottom.

"FINISHING. The surface of the concrete should be struck off by means of a template moved with a combined longitudinal and transverse motion. The excess material that accumulates in front of the template should be uniformly distributed over the surface of the pavement except near the transverse joint, when the excess material should be removed. The concrete adjoining the transverse joint shall be dense, and any depressions in the surface shall be filled with concrete of the same composition as the body of the work. After being brought to the established grade with a template, the concrete should be finished to true surface with a wood float, used from a suitable bridge. A metal float, trowel, should not be used. Brooming of the surface is not necessary, and grooves are objectionable even on grades.

"Retempering of mortar or concrete which has partly hardened, that is, mixing with additional materials or water, is strongly condemned and should not be permitted.

"Protection and Curing. Even the best concrete may be seriously damaged by too rapid drying out, early exposure to low temperature, or by being opened to traffic at too early a period. Hot sun and drying winds are most likely to dry out the concrete too rapidly, thus causing shrinkage cracks or causing a surface which will not wear well under traffic. The use of a canvas covering will be found effective in overcoming this condition. Sprinkling should also be employed as soon as the concrete is hard enough to prevent the surface from being pitted. An earth covering or protection by ponding should be employed after the first day. Under most favorable conditions such protection should be given to the pavement for at least 2 weeks. Water should be added during this period to keep the concrete wet. In cool weather it is often advisable to omit the earth covering, thus allowing the concrete to harden more rapidly. Sprinkling should not be omitted during the day in case the surface shows a tendency to dry out. When there is danger of frost, sprinkling should be omitted and a covering of canvas or of straw and canvas used. Placing concrete pavements in temperatures at or near freezing is not advisable; but if in special cases such work is unavoidable, the water and aggregate should be heated and fresh work protected, and precautions taken to protect the concrete from freezing for at least 10 days. Chemicals should not be used to lower the freezing temperature of the mixture. See (23a). Concrete should not be deposited on a frozen subgrade.

"Opening to Traffic. Under most favorable conditions a concrete pavement should not be opened to traffic in less than 2 weeks after the last concrete has been placed, and when conditions permit this interval should be increased to 4 weeks.

"Where the materials most readily available are such as to give good construction in one-course pavement, this Conference recommends that the one-course be used.

"The Integral Curb for concrete street pavements is recommended in preference to straight curb or combined curb and gutter. Such construction eliminates the

longitudinal joint along the curb, and maintains a permanent grade and alignment. Precaution should be taken to insure that the curb is thoroly bonded to the pavement proper. The integral curb can be used on wide as well as on narrow streets.

"**Specifications.** Since no specifications were considered by the Conference, the Standard Specifications for Pavements and Roadways of the Am. Concrete Inst. are recommended."

For a Tabular Comparison of Specifications of Coarse Aggregates, see (59). For additional specifications covering materials for cement-concrete for pavements, see Art. 10.

The Am. Concrete Inst. 1917 Specifications for One-Course Cement-Concrete Pavement for Roads are as follows:

"**Materials.** CEMENT. The cement shall meet the requirements of the Standard Specifications and Tests for Portland Cement, adopted by the Am. Soc. Test. Mat., Sept. 1, 1916, with all subsequent amendments and additions thereto adopted by said Society and by this Institute. See (69c).

"AGGREGATES. Before delivery on the job, the contractor shall submit to the engineer a 50 lb sample of each of the fine and coarse aggregates proposed for use. The samples shall be tested and if found to pass the requirements of the specifications similar material shall be considered as acceptable for the work. Aggregates containing frost or lumps of frozen material shall not be used.

"Fine aggregate shall consist of natural sand or screenings from hard, tough durable crushed rock or gravel, consisting of quartzite grains or other equally hard material, graded from fine to coarse with the coarse particles predominating. Fine aggregate, when dry, shall pass a screen having 4 meshes per lin in; not more than 25% shall pass a sieve having 50 meshes per lin in, and not more than 5% shall pass a sieve having 100 meshes per lin in. Fine aggregate shall not contain vegetable or other deleterious matter, nor more than 3% by weight of clay or loam. Routine field tests shall be made on fine aggregate as delivered. If there is more than 7% of clay or loam by volume in 1 hour's settlement after shaking in an excess of water, the material represented by the sample shall be rejected. Fine aggregate shall be of such quality that mortar composed of 1 part Portland cement, and 3 parts fine aggregate, by weight, when made into briquettes, shall show a tensile strength, at 7 and 28 days, equal to or greater than the strength of briquettes composed of 1 part of the same cement and 3 parts standard Ottawa sand by weight. The percentage of water used in making the briquettes of cement and fine aggregate shall be such as to produce a mortar of the same consistency as that of the Ottawa sand briquettes of standard consistency. In other respects all briquettes shall be made in accordance with the methods outlined in the Standard Specifications and Tests for Portland Cement, adopted by the Am. Soc. Test. Mat., Sept. 1, 1916.

"Coarse aggregate shall consist of clean, hard, tough, durable crushed rock or pebbles graded in size, free from vegetable or other deleterious matter, and shall contain no soft, flat or elongated particles. The size of the coarse aggregate shall be such as to pass a 2-in round opening and shall range from 2 in down, not more than 5% passing a screen having 4 meshes per lin in and no intermediate sizes shall be removed.

"MIXED AGGREGATE. Crusher run stone, bank run gravel or artificially prepared mixtures of fine and coarse aggregate shall not be used.

"WATER shall be clean, free from oil, acid, alkali or vegetable matter.

"All REINFORCEMENT shall be free from excessive rust, scale, paint or coatings of any character which will tend to destroy the bond.

"JOINT FILLER shall consist of prepared strips of fiber matrix and bitumen, or similar material of approved quality, ¼ in in thickness. Where the joints are protected with metal plates the joint filler shall be made to conform to the cross-section of the pavement, and where unprotected joints are used, the width of the joint filler shall be at least ½ in greater than the thickness of the pavement at any point. Prior to submitting bid the contractor shall obtain approval of the engineer for the joint filler which he proposes to use.

"JOINT PROTECTION PLATES. Soft steel plates for the protection of the edges of the concrete at transverse joints shall be not less than 2½ in in depth and not less than ⅛ in nor more than ¼ in average thickness. The plates shall be of such form as to provide for rigid anchorage to the concrete. The type and method of installation of joint protection plates shall be approved by the engineer.

"SHOULDERS. Materials for the construction of shoulders shall be described as desired by the engineer.

"Grading shall include all cuts, fills, ditches, borrow pits, approaches and all earth or rock moving for whatever purpose where such work is an essential part of or necessary to the prosecution of the contract.

"ENGINEER'S STAKES will be set by the engineer for the center line, side slopes, finished grade and other necessary points properly marked for the cut or fill. When the established grade is approached the final grade stakes will be set for which............ days' notice must be given to the engineer.

"FREE HAUL. Excess material shall be disposed of as directed by the engineer, the free haul not to exceed..........feet.

"OVER-HAUL. Materials hauled a greater distance than the free haul from the place of excavation shall be paid for at the rate of.......... cents per cubic yard for each additional..........feet.

"CUTS AND FILLS. In cuts the final grade shall be obtained by rolling with a roller weighing not less than 5 nor more than 10 tons. When a fill of 1 ft or less is required to bring the surface to grade, all vegetable matter shall be removed before making the fill. Embankments shall be formed of earth or other approved materials and shall be constructed in successive layers, the first of which shall extend entirely across from the toe of the slope on one side to the toe of the slope on the other side and successive layers shall extend entirely across embankments from slope to slope. Each layer, which shall not exceed 1 ft in depth, shall be thoroly rolled with a roller weighing not less than 5 nor more than 10 tons. The roller shall pass over the entire area of each layer of the fill at least twice. The sides of the embankment shall be kept lower than the center during all stages of the work and the surface maintained in condition for adequate drainage. The use of muck, quicksand, soft clay or spongy material which will not consolidate under the roller, is prohibited. When the material excavated from the cuts is not sufficient to make the fills shown on the plans, the contractor shall furnish the necessary extra material to bring the fills to the proper width and grade. When the earth work is completed, the cross-section of the road-bed shall conform to the cross-sectional drawings and profile attached hereto.

"All SLOPES must be properly dressed to lines given by the engineer.

"Drainage. The contractor shall construct such drainage ditches as will insure perfect surface and subsurface drainage during construction, and such work shall be completed to the satisfaction of the engineer, prior to the preparation of the road-bed, as herein specified.

"TILE DRAINS shall be placed as shown in the drawings attached hereto. Tile to be laid in a trench at least................ inches wide and..................... feet deep below the established grade of the finished road. Such trench shall be backfilled with crushed stone or pit run gravel, with fine material removed, which, after light tamping, shall be.................... inches in depth.

"OPEN DITCHES must be constructed along the concrete pavement as shown on the attached drawing; the dimensions, side slopes and grade of said ditches being as shown on the cross-section drawings and profile attached hereto. At the time of the acceptance of the road, or when concreting is discontinued for the winter, the ditches must be in perfect condition with clean slopes and bottom, containing no obstructions to the flow of water.

"The Subgrade shall be brought to a firm density by rolling the entire area with a self-propelled roller. All portions of the surface of the subgrade, which are inaccessible to the roller, shall be thoroly tamped with a hand tamp weighing not less than 50 lb, the face of which shall not exceed 100 sq in in area. All soft, spongy or yielding spots and all vegetable or other perishable matter shall be entirely removed and the space refilled with suitable materials. When the concrete pavement is to be constructed over an old road-bed composed of gravel or macadam, the old road-bed shall be entirely loosened and the material spread for the full width of the road-bed and rolled. All interstices shall be filled with fine material and rolled to make a dense, tight surface of the road-bed.

"ACCEPTANCE. No concrete shall be deposited until the subgrade is checked and accepted by the engineer.

"Forms. MATERIALS. Metal or wooden forms shall be free from warp, of sufficient strength to resist springing out of shape, and shall be equal in width to the thickness

of the pavement at the edges. Wooden forms shall be of not less than 2-in stock, and shall be capped with 2-in angle irons.

"SETTING. The forms shall be well staked or otherwise held to the established line and grades, and the upper edges shall conform to the established grade of the road.

"TREATMENT. All mortar and dirt shall be removed from forms before they are used.

"**Pavement Section.** WIDTH, THICKNESS OF CONCRETE AND CROWN. The concrete pavement shall be .... feet wide, ... inches in depth at center, and .... inches in depth at the sides. The finished surface shall conform to the arc of a circle, as shown on the plans attached hereto.

"NOTE: The thickness of the concrete at the edges shall be not less than 6 in. The crown shall be not less than 1/100 nor more than 1/50 of the width.

"**Joints.** WIDTH AND LOCATION. Transverse joints shall be ¼ in in width and shall be placed across the pavement perpendicular to the center line, not more than 36 ft apart. All joints shall extend thru the entire thickness of the pavement and shall be perpendicular to its surface. All catch-basins, manhole tops, poles or other fixed objects which project thru the pavement shall be separated from the concrete by joint filler.

"JOINT FILLER. All joints shall be formed by inserting during construction and leaving in place the required thickness of joint filler which shall extend thru the entire thickness of the pavement.

"PROTECTED JOINTS.* The concrete at all transverse joints shall be protected with joint protection plates which shall be rigidly anchored to the concrete. The upper edges of the plates shall be even with each other and the adjoining surface of the concrete. All steel plates varying more than ¼ in from the finished surface of the concrete, as shown on the plans attached hereto, shall be ground to meet the specified requirements, or slabs in which such plates occur shall be removed and replaced with new material by the contractor at his expense.

"UNPROTECTED JOINTS.* All transverse joints shall extend thru the entire thickness of the pavement and the filler shall project not less than ½ in above the finished surface. Before the road is opened to traffic, joint filler shall be cut off to a height of ¼ in above the surface of the road.

"**Measuring Materials and Mixing Concrete.** MEASURING MATERIALS. The method of measuring the materials for the concrete, including water, shall be one which will insure separate and uniform proportions of each of the materials at all times. A sack of Portland cement, 94 lb net, shall be considered 1 cu ft.

"MIXING. The materials shall be mixed in a batch mixer approved by the engineer, and irrespective of the size of the batch and rate of speed used, mixing shall continue after all materials are in the drum for at least 1 min before any part of the batch is discharged from the drum. The drum shall be completely emptied before receiving material for the succeeding batch. The volume of the mixed material used per batch shall not exceed the manufacturer's rated capacity of the drum in cubic feet of mixed material.

"RETEMPERING. Retempering of mortar or concrete which has partly hardened; that is, remixing with or without additional materials or water, shall not be permitted.

"PROPORTIONS. The concrete shall be mixed in the proportions of 1 sack of Portland cement to not more than 2 cu ft of fine aggregate and not more than 3 cu ft of coarse aggregate, and in no case shall the volume of the fine aggregate be less than one-half the volume of the coarse aggregate. A cubic yard of concrete in place shall contain not less than 1.7 barrels of cement. The engineer shall compare the calculated amount of cement required according to these specifications and plans attached hereto with the amounts actually used in each section of concrete between successive transverse joints, as determined by actual count of the number of sacks of cement used in each section. If the amount of cement used in any three adjacent sections, between transverse joints, is less by more than 2%, or if the amount of cement used in any one section is less by more than 5% of the amount hereinbefore required, the contractor

"*NOTE: When the specification Protected Joints is to be used, Unprotected Joints should be omitted, and vice versa.

shall remove all such sections and replace the same with new materials, according to these specifications, at his expense.

"CONSISTENCY. The materials shall be mixed with sufficient water to produce a concrete which will hold its shape when struck off with a template. The consistency shall not be such as to cause a separation of the mortar from the coarse aggregate in handling.

"Reinforcing. Concrete pavements 20 ft or more in width shall be reinforced. The reinforcement shall have a weight of not less than 28 lb per 100 sq ft. The ratio of effective areas of reinforcing members at right angles to each other may vary from 1:1 to 4:1. The spacing between parallel lines of reinforcing members shall not be more than 8 in. A reduction of 3 lb from the weight specified shall be allowed for those types of reinforcement not requiring extra metal at intersections.

"NOTE: The committee is of the opinion that the weight of reinforcement for streets over 25 ft wide should be greater than 28 lb per 100 sq ft.

"Reinforcing metal shall be placed not less than 2 in from the finished surface of the pavement and otherwise shall be placed as shown on the drawings attached hereto. The reinforcing metal shall extend to within 2 in of all joints, but shall not cross them. Adjacent widths of fabric shall be lapped not less than 4 in when the lap is made perpendicular to the center line of the pavement and not less than 1 ft when the lap is made parallel to the center line of the pavement, and in most cases the use of reinforcement in pavements 16 ft wide is good practice.

"Placing Concrete. Immediately prior to placing the concrete, the subgrade shall be brought to an even surface. The surface of the subgrade shall be thoroly wet but shall show no pools of water when the concrete is placed. After mixing, the concrete shall be deposited rapidly upon the subgrade, to the required depth and for the entire width of the pavement in successive batches and in a continuous operation without the use of intermediate forms or bulkheads between expansion joints. If concrete is placed in two courses, as when reinforcement is used, any dirt, sand or dust which collects on the base course, shall be removed before the top course is placed. The concrete above the reinforcement shall be placed immediately after mixing and in no case shall more than 45 min elapse between the time that the concrete below the reinforcement has been mixed and the concrete above the reinforcement is placed. In case of a breakdown, concrete shall be mixed by hand to complete the section or an intermediate transverse joint placed as hereinbefore specified at the point of stopping work. Any concrete in excess of that needed to complete a section at the stopping of work shall not be used.

"FINISHING. The concrete shall be brought to a proper contour by any means which will insure a compact dense surface. Any holes left by removing any material or device used in constructing joints shall be filled immediately with concrete from the latest batch deposited on the subgrade. Concrete adjoining metal protection plates at transverse joints shall be dense in character and shall be given a smooth finish with a steel trowel for a distance of 6 in on each side of the joints. The concrete adjacent to unprotected joints shall be finished with a wood float, which is divided thru the center and which will permit finishing on both sides of the filler at the same time. Concrete shall be finished in a manner thoroly to compact it and produce a surface free from depressions or inequalities of any kind. The finished surface of the pavement shall not vary more than ¼ in from the specified contour.

"NOTE: It is recommended that the contractor be required at the end of each day's work to stamp in the surface of the concrete, with letters 1½ to 2 in high and ¼ in deep, the date and his name.

"Protection. CURING AND PROTECTION. Except as hereinafter specified, the surface of the pavement shall be sprayed with water as soon as the concrete is sufficiently hardened to prevent pitting, and shall be kept wet until an earth or other approved covering is placed. As soon as it can be done without damaging the concrete, the surface of the pavement shall be covered with not less than 2 in of earth or other material approved by the engineer, which cover shall be kept wet for at least 10 days. When deemed necessary or advisable by the engineer, freshly laid concrete shall be protected by canvas until such covering can be placed. Under the most favor conditions for hardening in hot weather the pavement shall be closed to traffic least 14 days, and in cool weather for an additional time, to be determine engineer. When the average temperature is below 10° C (50° F), sprinklin

ering of the pavement may be omitted at the discretion of the engineer. The contractor shall erect and maintain suitable barriers to protect the concrete from traffic and any part of the pavement damaged from traffic or other causes, occurring prior to its official acceptance, shall be repaired or replaced by the contractor at his expense, in a manner satisfactory to the engineer. Before the pavement is thrown open to traffic the covering shall be removed and disposed of as directed by the engineer.

"COLD WEATHER WORK. Concrete shall not be mixed nor deposited when the temperature is below freezing. If, at any time during the progress of the work, the temperature is, or in the opinion of the engineer will within 24 hr drop to 2° C (35° F), the water and aggregates shall be heated, and precautions taken to protect the work from freezing for at least 10 days. In no case shall concrete be deposited upon a frozen subgrade.

"**Shoulders.** CONSTRUCTION. When shoulders are required, they shall be built upon the properly prepared subgrade, as shown on the profile and cross-sectional drawings attached hereto. The work shall be done to the entire satisfaction of the engineer."

Am. Concrete Inst. 1917 Specifications for One-Course Cement-Concrete Pavement for Streets. Note: All essentials of the specifications for One-Course Cement-Concrete Pavement for Roads applicable to street pavements, except those having the same titles as sections hereafter given, form a part of these specifications.

Materials. JOINT FILLER. Essentially the same as for One-Course Cement-Concrete Pavement for Roads and, in addition, as follows: "The filler for longitudinal joints along the curb, where a separate curb is used, shall, at the discretion of the engineer, consist of the same material as specified for the transverse joints or of bitumen which will not become soft enough to flow in hot weather or brittle in cold weather. The thickness of longitudinal joints filled with bitumen shall be not less than ¼ nor more than ¾ in.

Grading. CUTS AND FILLS. Essentially the same as for One-Course Cement Concrete Pavements for Roads and, in addition, as follows: "All approaches connecting the specified pavement with other streets or alleys intersecting shall also be cut or filled, and secured from settlement, to form a slope of not more than 1 vertical to 10 horizontal, as shown on the profile and plans attached hereto.

"**Drainage.** CATCH-BASINS. All catch-basin and manhole tops and all covers or openings of any kind shall be adjusted to the grade by the contractor at the price shown under this item in his bid.

"**Forms.** SETTING. The forms shall be well staked or otherwise held to the established line and grades. Where the curb is to be constructed integrally with the pavement, the upper edge of the side forms shall conform to the top of the curb.

"**Pavement Section.** WIDTH, THICKNESS OF CONCRETE AND CROWN. The concrete pavement shall be............feet wide from face to face of curb,............inches in depth at the center and..............inches in depth at the sides. The finished surface shall conform to the arc of a circle as shown on the plans attached hereto.

"NOTE: The thickness of the concrete at the sides shall be not less than 6 in and at the center not less than 2 in more than the thickness at the sides. When pavements 20 ft or less in width are to be built on approximately level ground and a flat subgrade is to be used, sufficient fall for drainage at the sides of the pavement along the curb shall be provided by giving the road-bed the same grade as that proposed for the gutter. The crown shall be not less than 1/100 nor more than 1/50 of the width.

Joints. WIDTH AND LOCATION. Same as for One-Course Cement-Concrete Pavement for Roads except as follows: "A longitudinal joint not less than ¼ in wide shall be constructed between the curb and the pavement where a separate curb is used. All joints shall extend thru the entire thickness of the pavement and curb, when integral curb is specified and shall be perpendicular to the surface of the pavement. In pavements with integral curb, the joint shall be continuous in a straight line thru pavement and curb.

"JOINT FILLER. All transverse joints shall be formed by inserting during construction and leaving in place the required thickness of prepared strips of fiber matrix and bitumen or similar material of approved quality which shall extend thru the entire thickness of the pavement and the entire thickness and height of the integral curb when the latter is specified. Longitudinal joints along the curb, where a separate

curb is specified, shall, at the discretion of the engineer, be formed in the same manner as transverse joints or constructed by filling with bitumen as before specified.

"**Integral Curb.** CONSTRUCTION. An integral curb shall be constructed, as shown on the attached drawings, to the established grade and in a continuous line on each side of the street ....feet from and parallel with the center line thereof, except at all intersections of streets, alleys and driveways where it shall be returned to the street line, and at these intersections it shall be rounded to such a radius as the engineer may direct. The concrete for integral curbs shall be of the same materials and proportions as that required for the pavement. After striking off the pavement, the concrete for that portion of the integral curbs above the gutter line shall be immediately deposited. The top and inside surface of integral curbs shall be given a smooth finish and completed with the pavement to the point of stopping each day's work."

"NOTE: Above paragraph to be omitted if separate curb is specified."

Am. Concrete Inst. 1917 Specifications for Two-Course Cement-Concrete Pavement for Streets. Note: All essentials of the specifications for One-Course Cement-Concrete Pavement for Streets, except those having the same titles as sections hereinafter given, form a part of these specifications.

Aggregates. The same as for One-Course Cement-Concrete Pavement for Streets and, in addition, as follows:

"NO. 1 AGGREGATE FOR WEARING COURSE: No. 1 aggregate for the wearing course shall consist of clean, hard, tough, durable crushed rock or pebbles, free from vegetable matter, and shall contain no soft, flat or elongated particles. It shall pass, when dry, a screen having ½-in openings and not more than 10% shall pass a screen having ¼-in openings.

"NO. 2 AGGREGATE FOR WEARING COURSE: No. 2 aggregate for the wearing course shall consist of clean, hard, tough, durable crushed rock or pebbles graded in size, free from vegetable or other deleterious matter, and shall contain no soft, flat or elongated particles. The size of No. 2 coarse aggregate shall be such as to pass a 1-in round opening and shall range from 1-in down, not more than 5% passing a screen having 4-meshes per lin in and no intermediate sizes shall be removed.

Pavement Section. WIDTH, THICKNESS OF CONCRETE AND CROWN. Essentially the same as for One-Course Cement-Concrete Pavement for Streets and, in addition, as follows:

"NOTE: The thickness of the concrete base at the sides shall be not less than 5 in and at the center not less than 2 in more than the thickness at the sides. The thickness of the wearing course shall be not less than 2 in.

"**Measuring Materials and Mixing Concrete.** CONSISTENCY. The materials for the pavement shall be mixed with only sufficient water to produce a concrete which will hold its shape when struck off with a template. The consistency shall not be such as to cause a separation of the mortar from the aggregate in handling.

"CEMENT REQUIRED. A cubic yard of concrete base in place shall contain not less than 1.4 barrels of cement. A cubic yard of No. 1 Mix Wearing Course in place shall contain not less than 2.97 barrels of cement, and a cubic yard of No. 2 Mix Wearing Course in place shall contain not less than 2.1 barrels of cement. The engineer shall compare the calculated amount of cement required according to these specifications and plans attached hereto with the amounts actually used in each section of concrete, including integral curbs when used, between successive transverse joints, as determined by actual count of the number of sacks of cement used in each section. If the amount of cement used in any three adjacent sections, between transverse joints, is less by more than 2%, or if the amount of cement used in any one section is less by more than 5% of the amount hereinbefore required, the contractor shall remove all such sections and replace the same with new materials, according to these specifications, at his expense.

"**Concrete for Base.** PROPORTIONS. The concrete shall be mixed in the proportions of 1 sack of Portland cement to not more than 2½ cu ft of fine aggregate, and not more than 4 cu ft of coarse aggregate, and in no case shall the volume of the fine aggregate be less than one-half the volume of the coarse aggregate.

PLACING CONCRETE. Essentially the same as for One-Course Cement-Concrete Pavement for Streets and, in addition, as follows: "The concrete shall be brought to

an even surface, the thickness of the wearing course below the established grade of the pavement. If dirt, sand or dust collects on the base it shall be removed before the wearing course is applied. The reinforcing metal shall be placed upon and slightly pressed into the concrete base immediately after it is placed.

"Concrete for Wearing Course. PROPORTIONS FOR MIXTURE NO. 1*. The concrete for the wearing course shall be mixed in the manner hereinbefore specified in the proportions of 1 sack of Portland cement to not more than 1 cu ft of fine aggregate, and not more than 1½ cu ft of No. 1. Aggregate for Wearing Course and in no case shall the volume of the fine aggregate be less than one-half the volume of the No. 1 Aggregate for Wearing Course.

"PROPORTIONS FOR MIXTURE NO. 2.* The concrete for the wearing course shall be mixed in the manner hereinbefore specified in the proportions of 1 sack of Portland cement to not more than 1½ cu ft of fine aggregate and not more than 2½ cu ft of No. 2. Aggregate for Wearing Course hereinbefore specified, and in no case shall the volume of the fine aggregate be less than one-half the volume of No. 2 Aggregate for Wearing Course.

"PLACING. The wearing course shall be placed immediately after mixing and in no case shall more than 45 min elapse between the time that the concrete for the base has been mixed and the time the wearing course is placed.

Integral Curb. Essentially the same as for One-Course Cement-Concrete Pavement for Streets and, in addition, as follows: "The concrete for that portion of the integral curbs above the base shall be of the same materials and proportions as that specified for the wearing course."

Am. Concrete Inst. 1917 Specifications for One-Course Cement-Concrete Pavement for Alleys. Note: All essentials of the specifications for One-Course Cement-Concrete Pavement for Streets, except those having the same titles as sections hereinafter given, form a part of these specifications.

"Forms. MATERIALS. Metal or wooden forms shall be free from warp, of sufficient strength to resist springing out of shape, and shall be equal in width to the thickness of the pavement at the edges. Wooden forms shall be of not less than 2-in stock. Where the pavement is laid adjacent to buildings, fences or other structures, the side forms may be omitted at the direction of the engineer, but a joint must be constructed as hereinafter specified, between the pavement and such structure.

"Pavement Section. WIDTH, THICKNESS OF PAVEMENT AND CROSS-SECTION. The width of the pavement shall be................feet inches, and not less than 6 in uniform thickness. In cross-section the finished surface shall have a uniform pitch toward the center line, except that the center 12 in shall be rounded to the arc of a circle which is tangent to the surface of the concrete at points 6 in on each side of the center line, as shown in the plans attached hereto. The dish shall not exceed 1/30 of the width of the pavement."

Am. Soc. Mun. Imp. 1917 Specifications for a One-Course Pavement† are as follows:

"Materials. CEMENT. The cement shall meet the requirements of the Standard Specifications for Portland Cement, adopted by the Am. Soc. Test. Mat., August 16, 1909, with all subsequent amendments and additions thereto adopted by said Society.

"FINE AGGREGATE. Sand. Fine aggregate shall consist of natural sand or screenings from hard, tough, durable crushed rock or gravel, consisting of quartzite grains or other equally hard material graded from fine to coarse, with the coarse particles predominating. Fine aggregate, when dry, shall pass a sieve having 4 meshes per lin in; not more than 25% shall pass a sieve having 50 meshes per lin in, and not more than 5% shall pass a sieve having 100 meshes per lin in. Fine aggregate shall not contain vegetable or other deleterious matter nor more than 3% of clay or loam. Fine aggregate shall be of such quality that mortar composed of 1 part Portland cement and 3 parts of fine aggregate, by weight, when made into briquettes, shall show a tensile

"*NOTE: When Mixture No. 1 is specified, specifications for Mixture No. 2 should be omitted, and vice versa.

"†Specifications regarding both joints and reinforcement are purposely omitted from these specifications, in order that the freest opportunity may be afforded for their addition, in any particular case, according to the opinions of the engineers in charge, dependent upon local conditions.

strength, at 7 and 28 days, at least equal to the strength of briquettes composed of 1 part of the same cement and 3 parts standard Ottawa sand by weight. The percentage of water used in making the briquettes of cement and fine aggregate shall be such as to produce a mortar of the same consistency as that of the Ottawa sand briquettes of standard consistency. In other respects, all tests shall be made in accordance with the prevailing Report of the Committee on Uniform Tests of Cement of the Am. Soc. C. E.

"COARSE AGGREGATE shall consist of clean, tough, crushed rock or pebbles, or slag of approved quality in graded sizes, free from vegetable or other deleterious matter and containing no soft, flat or elongated particles. The sizes of the coarse aggregate shall be such as to pass a 1½-in round opening, and shall range from 1½ in down, not more than 5% passing a ¼-in round opening, and with no intermediate sizes removed.

"**Proportions.** All proportions of cement, fine aggregate and coarse aggregate shall be determined on the basis of volumetric analysis, with a view to obtaining a uniform density for the resulting concrete. Voids in the fine aggregate shall be determined by saturation and not less than 20% more cement shall be employed than the volume of voids thus determined; in no case shall the proportions of cement and fine aggregate be leaner than 1: 2. The voids in the coarse aggregate shall be determined by saturation and not less than 20% more mortar shall be employed than the volume of voids thus determined.

"**Water** shall be clean, free from oil, acid, alkali, vegetable matter and other deleterious substances.

"**Subgrade.** CONSTRUCTION. The bottom of the excavation or the top of the fill when completed shall be known as the subgrade and shall be at all places true to the elevation as shown on the plans attached hereto. The subgrade shall be brought to a firm, unyielding surface by rolling the entire area with a self-propelled roller weighing not less than 5 tons, and all portions of the surface of the subgrade, which are inaccessible to the roller, shall be thoroly tamped with a hand tamp weighing not less than 50 lb, the face of which shall not exceed 100 sq in in area. All soft, spongy, or yielding spots and all vegetable or other perishable matter shall be entirely removed and the space refilled with suitable material. When considered necessary or of assistance in producing a compact, solid surface, the subgrade before being rolled shall be well sprinkled with water. When the concrete pavement is to be constructed over an old pavement composed of gravel or macadam, the latter shall be entirely loosened and the material spread for the full width of the pavement and rolled. All interstices shall be filled with fine material and rolled to make a dense, tight surface.

"ACCEPTANCE. No concrete shall be deposited until the subgrade is checked and accepted by the engineer.

"**Forms.** MATERIALS. Where forms are required, they shall be free from warp, of sufficient strength to resist springing out of shape. Wooden forms shall be of not less than 2-inch stock.

"SETTING. The forms shall be well staked or otherwise held to the established line and grades. Where the curb is to be constructed integrally with the pavement, the upper edge of the side forms shall conform to the top of the curb.

"TREATMENT. All mortar and dirt shall be removed from the forms that have previously been used. Precautions shall be taken to prevent leaks thru side forms that would allow the cement or mortar to be carried out of the coarser aggregate along the edges of the roadway.

"**Measuring Materials and Mixing Concrete.** MEASURING MATERIALS. The method of measuring the materials for the concrete, including water, shall be one which will insure separate and uniform proportions of each of the materials at all times. A bag of Portland cement, 94 lb net, shall be considered 1 cu ft.

"MIXING. The materials shall be mixed in a batch mixer of approved type and mixing shall continue after all materials are in the drum for at least 1 min at a minimum speed of 12 rev per min. The drum shall be completely emptied before receiving materials for successive batches.

"RETEMPERING of mortar or concrete which has partially hardened, that is, remixing with or without additional materials or water, shall not be permitted.

"**Placing Concrete.** Immediately prior to placing the concrete, the subgrade shall be brought to an even surface. The surface of the subgrade shall be thoroly wetted. After mixing, the concrete shall be deposited rapidly upon the subgrade to the required depth and for the entire width of the pavement in successive batches and in a

continuous operation without the use of intermediate forms or bulkheads between expansion joints. In case of a breakdown, concrete shall be mixed by hand to complete the section or an intermediate transverse joint placed at the point of stopping work. Any concrete in excess of that needed to complete a section at the stopping of work shall not be used in the work.

"FINISHING. The surface of the concrete shall be struck off for the entire width of the pavement and from back to back of integral curbs when used, by means of a template or strike-board. Any holes left by removing any material or device used in constructing the joint shall be immediately filled with mortar composed of 1 part cement and 2 parts of fine aggregate. Concrete adjoining metal protection plates of transverse joints shall be dense in character and shall be given a smooth finish with a steel trowel for a distance of 6 in on each side of the joints. After being brought to the established grade with the template or strike-board, the concrete shall be finished from a suitable bridge, no part of which shall come in contact with the concrete. If approved by the engineer, the contractor may use a mechanical striking and finishing machine. The concrete shall be finished with a wood float in a manner to thoroly compact it and produce a surface free from depressions or inequalities of any kind. The finished surface of the pavement shall not vary more than ¼ in from the true shape.

"Protection. Excepting as hereinafter specified, the surface of the pavement shall be sprayed with water as soon as the concrete is sufficiently hardened to prevent pitting, and shall be kept wet until an earth or other approved covering is placed. As soon as it can be done without damaging the concrete, the surface of the pavement shall be covered with not less than 2 in of earth or other material approved by the engineer, which cover shall be kept wet for at least 10 days. When deemed necessary or advisable by the engineer, freshly laid concrete shall be protected by the canvas until such covering can be placed. Under the most favorable conditions for hardening in hot weather, the pavement shall be closed to traffic for at least 14 days and in cool weather for an additional time, to be determined by the engineer. At the season of the year when the average temperature is below 10° C (50° F), sprinkling and covering of the pavement may be omitted at the direction of the engineer. The contractor shall erect and maintain suitable barriers to protect the concrete from traffic and any part of the pavement damaged from traffic or other causes, occurring prior to its official acceptance, shall be required or replaced by the contractor at his expense, in a manner satisfactory to the engineer. Before the pavement is thrown open to traffic the covering shall be removed and disposed of as directed by the engineer.

"TEMPERATURE BELOW 2° C (35° F). Concrete shall not be mixed or deposited when the temperature is below freezing. If at any time during the progress of the work the temperature is, or in the the opinion of the engineer will, within 24 hr drop to 2° C (35° F), the water and aggregates shall be heated, and precautions taken to protect the work from freezing for at least 10 days. In no case shall concrete be deposited upon a frozen subgrade."

Am. Soc. Mun. Imp. 1917 Specifications for Two-Course Cement-Concrete Pavement. Note: All essentials of the specifications for One-Course Cement-Concrete Pavement, except those having the same titles as sections hereinafter given, form a part of these specifications.

"Materials. No. 1 Coarse Aggregate for the Wearing Course shall consist of that portion of the coarse aggregate, which, when dry, will pass a ½-in round opening and contain not more than 10% of the fine material which will pass a ¼-in round opening.

"No. 2 Coarse Aggregate for the Wearing Course shall consist of that portion of the coarse aggregate, which will pass a 1-in round opening, ranging in size from 1 in down and containing not more than 5% of fine material that will pass a ¼-in round opening, and with no intermediate sizes removed.

"Proportions. All proportions of cement, fine aggregate and coarse aggregate shall be determined on the basis of volumetric analysis with a view to obtaining a uniform density for the resulting concrete.

"BASE. The voids in the fine aggregate shall be determined by saturation and not less than 10% more cement shall be employed than the volume of voids thus determined; in no case shall the proportions of the cement and fine aggregate be leaner than 1:1½. The voids in the coarse aggregate shall be determined by saturation and not less than 20% more mortar shall be employed than the volume of voids thus determined.

"WEARING SURFACE. The coarse aggregate in the wearing surface shall be No. 1 or No. 2 as specified above. The voids in the fine aggregate shall be determined by saturation and not less than 20% more cement shall be employed than the volume of voids thus determined; in no case shall the proportion of cement to fine aggregate be leaner than 1:2. The voids in the coarse aggregate shall be determined by saturation and not less than 20% more mortar shall be employed than the volume of voids thus determined.

Placing Concrete for Base. Essentially the same as the section on Placing Concrete in specifications for One-Course Cement-Concrete Pavement and, in addition, as follows: "The concrete shall be brought to an even surface, the thickness of the wearing course, below the established grade of the pavement. Workmen shall not be allowed to walk on the freshly laid concrete, and if sand or dust collects on the base, it shall be removed before the wearing course is applied. The reinforcing metal shall be placed upon and slightly pressed into the concrete base immediately after it is placed.

"**Concrete for the Wearing Course.** MIXTURE NO. 1. The concrete for the wearing course shall be mixed in the manner and of the proportions hereinbefore described, using for the coarse aggregate No. 1 aggregate for the wearing course hereinbefore specified.

"MIXTURE NO. 2. The concrete for the wearing course shall be mixed in the manner and of the proportions hereinbefore described, using for the coarse aggregate No. 2 aggregate for the wearing course, herein specified.

"PLACING. The wearing course shall be placed immediately after mixing, and in no case shall more than 45 min elapse between the time that the concrete for the base has been mixed and the time the wearing course is placed."

16. Construction Cost Data

First Cost depends so much on local conditions that a bald statement in figures is apt to be entirely misleading unless the conditions are well understood or a further statement of them is comprehensively made. The cost of a concrete foundation, even of a thickness as low as 4 in is scarcely ever less than 50 cents per sq yd, and the cost of a concrete roadway could therefore not be less than this figure. On the other hand, a concrete roadway might cost, under unfavorable but possible conditions, as high as $2 per sq yd.

The Report of Com. XII, 1914 Nat. Conf. Concrete Road Building included the following: See also (50m).

"Altho numerous inquiries were sent out by your Committee for information, there has not been received as yet any large amount of cost data except from the Mich. State Dept., Wayne County, and the Ill. Highway Dept. The Committee has therefore confined itself to averaging the cost of work reported in the different States, confining the comparison to the one-course construction. These data are presented herewith in Table V.

"There are also presented four diagrams: (1) showing the distribution of cost data on concrete roads built 1909-1912, as reported by the State Highway Dept. of Mich.; (2) is a similar diagram compiled from cost data reported on the concrete road work done in Wayne County, Mich., in 1912 and 1913; (3) is a similar diagram for the work done in 1912-1913 by the Ill. Highway Comm.; (4) is the average of all the data from which the first three diagrams were made, taking due account of the relative amount of work done in each instance." The information in the diagrams referred to in the Committee's report is given in tabular form below:

Table V.—Average Cost of One-Course Concrete Pavement

State	Cost per Sq Yd
Arizona	$1.20
Arkansas	0.90
California	1.17
Colorado	1.25
Connecticut	1.32
Delaware	1.61
Idaho	1.09
Illinois	1.01
Indiana	1.23
Iowa	1.11
Kansas	1.08
Maine	1.48
Maryland	1.21
Massachusetts	1.29
Michigan	1.27
Minnesota	1.05
Missouri	1.17
Montana	1.83
Nebraska	1.40
New Jersey	1.12
North Dakota	1.26
Ohio	1.22
Oklahoma	1.05
Oregon	1.39
Pennsylvania	1.16
Tennessee	1.20
Washington	1.31
West Virginia	1.32
Wisconsin	1.06
Average Total	$1.24
Weighted Total Average	$1.19

Table VI.—Showing Division of Total Costs per Square Yard of One-Course Cement-Concrete Roadways

Item	A Average of 7 Pavements in Michigan, Built 1909–12 from Report by Rogers		B Average of 8 Sections Wayne Co., Michigan, Built 1912–13		C Construction by Illinois Highway Commission 1912–13		Weighted Mean of Columns A, B and C	
Labor								
Mixing and placing...					11.6%			
Unloading and hauling					13.1			
Shaping and trimming					6.8			
Superintendence and miscellaneous......					7.0			
Total.............		43.0%		46.0%		38.5%		44.3%
Materials.............								
Aggregate...........	29.0%		27.0%		25.2%		27.7%	
Cement.............	22.7		19.9		31.7		21.6	
Expansion joints.....	....		....		2.3		6.4	
Miscel. Supplies......	5.3		7.1		2.3			
Total...........		57.0%		54.0%		61.5%		55.7%
Grand total.......		100.0%		100.0%		100.0%		100.0%

It should be noted that in the cost figures given no statement is made as to just what the figures include, that is, whether costs per square yard cover simply the furnishing, mixing and placing of the concrete itself, or whether they also cover the incidental work of preparing the subgrade, finally trimming up the shoulders, the overhead charges, etc. Further in applying to estimates the information given by the percentage table, it should be remembered that these percentages have been obtained from figures of cost not varying widely from an average figure and that the division into percentages of total cost might be materially altered where it could reasonably be expected that the total figure would for any reason vary greatly from the average on which those given are based. Further information as to costs reported may be had by reference to (17), (22), (26a), (28a), (32), (38) and (52a). For a discussion of the problems of estimating costs, see (50t).

Cost Analysis of Two-Course Pavement (22). "The following detailed cost analysis is for a 1:1½:3 concrete slab 6 in thick with a No. 29 American wire reinforcement placed 2 in from the top of the pavement. Transverse expansion joints were located at 33-ft intervals, and a longitudinal joint was placed along the middle of the 48-ft street between the 8-ft parkings. A ⅜-in felt strip was placed between the plates and in the joints without plates along the gutters. Weather conditions were, on the whole, favorable. The average rate of progress maintained while working was 720 sq yd per day of 8 hr. Including delays by rain and repairs, the average rate for the entire period was only 500 sq yd per day. Deposition of 864 sq yd was the largest day's work. Labor for mixing and placing concrete cost per sq yd = 79.75 ÷ 720 = $0.111. Plowing with steam roller in well compacted road cost 1 cent per sq yd for each time over. Two or three times over was the rule. Rough grading cost 18 cents per sq yd, exclusive of plowing. Fine grading cost 3 cents per sq yd. Rolling with 10-ton roller cost 0.3 cent per sq yd.

Table VII.—Cost Analysis 6-in Pavement per Square Yard

Materials		
Cement, 0.32 bbl at $1.20, f. o. b. cars........................	$0.384	
Sand, 0.080 cu yd at $1.10, delivered........................	0.088	
Stone, 0.14 cu yd at $1.21, f. o. b. cars........................	0.169	
Wire reinforcement at $0.76 per 100 sq ft........................	0.070	
Joint material at $0.15 per lin ft........................	0.050	
Total materials........................		$0.761

Labor

Grading, 12 in of excavation on average	$0.250	
Unloading and hauling materials 0.5 miles:		
Cement	0.032	
Stone	0.039	
Wire	0.005	
Joints	0.003	
Mixing and placing concrete	0.111	
Spreading and removing earth covering, 2 in thick	0.008	
Sprinkling, for 10 days	0.005	
Total labor		0.453

Plant and Supplies

Mixer rental at $10 per day	$0.020	
Fuel, oil and repairs	0.010	
Canvas, boots and other supplies and tools	0.020	
Total, plant and supplies		0.050
Overhead		0.050
Total cost per square yard		$1.314

Detailed Labor Cost Mixing and Placing Concrete

16 men shoveling and wheeling at 25 cents per hr	$32.00
2 men handling cement at 25 cents per hr	4.00
2 men handling wire and joints at 25 cents per hr	4.00
4 men handling strike-board at 25 cents per hr	8.00
5 men shoveling concrete around chute at 25 cents per hr	10.00
1 foreman at 50 cents per hr	4.00
Engineer and fireman on mixer, per hr	6.00
2 finishers at 50 cents per hr	8.00
Superintendent and timekeeper, ½ time	3.75
Total	$79.75"

Table VIII.—Character and Cost of Cement-Concrete Pavements Laid in 1915 in Several Cities

From *Engineering and Contracting*, April 5, 1916

City	Sq Yd	Type	Total Thickness in In	Price Per Sq Yd Including Grading	Guarantee in Years	Bottom Course or One-Course: Thickness in In	Bottom Course or One-Course: Proportions
Lynn, Mass.	43 982	1-course	5	1.23	..	5	1 : 2 : 5
Meriden, Conn.	17 780	1-course	7	1.32	..	7	1 : 1½: 3
No. Tonawanda, N.Y.	17 796	1-course	8	1.60	3	..	1 : 1½: 3
Baltimore, Md.	7 839	1-course	6	1.25	5	5	1 : 2 : 4
Fort Wayne, Ind.	3 090	2-course	7	1.40	5	5	1 : 2 : 4
Ironton, Ohio	16 105	1-course	7	1.67	5	7	1 : 1½: 3
Belleville, Ill.	40 000	2-course	8	1.45	..	..	1 : 2½: 4
Detroit, Mich.	137 379	2-course	7	2.31	5	6	1 : 3 : 6
Superior, Wis.	155 000	2-course	7½	1.32	5	5	1 : 2½: 5
Minneapolis, Minn.	44 165	1-course	7	1.30	..	7	1 : 2 : 4
Sioux City, Iowa	135 000	1-course	6	1.13	..	6	1 : 2½: 4
Springfield, Mo.	8 167	1-course	5	1.14	5	5	1 : 2 : 4
Sioux Falls, S. D.	7 242	2-course	7	1.80	2	..	1 : 2½: 5
Lincoln, Neb.	3 157	2-course	6	1.38	2	4	1 : 3 : 6
Atchison, Kan.	8 000	2-course	6	1.25	5	5	1 : 2½: 5
Athens, S. C.	14 000	2-course	7	1.11	..	5	1 : 3 : 5
Santa Ana, Cal.	3 820	1-course	5	1.98	..	5	1 : 2 : 4
Portland, Ore.	30 461	1-course	6	1.21	..	6	1 : 2 : 4
Everett, Wash.	14 579	1-course	6	1.10	..	6	1 : 2 : 3

17. Special Types of Cement-Concrete Pavements

Grouted Cement-Concrete Pavements. Grouting the aggregate in place is one of the two general methods of construction which may be said to be in use. This method consists of placing the broken stone, gravel or other coarse aggregate on the prepared subgrade, to its necessary total thickness, and then filling the voids of this material with a mixture of sand, Portland cement and water, called grout. The concrete built in this way is thus built in one course, tho the aggregate may be spread and compacted in two layers, and rolling either before or during the grouting, or both, accompanies the process.

THE HASSAM PAVEMENT is a widely known example of this form of construction. Under the Hassam process, the subgrade is prepared as for macadam, the aggregate spread and rolled as in the case of macadam, and then instead of filling the voids in the aggregate with screenings or fine material by the aid of watering and rolling, the rolled aggregate is grouted with the thin mortar referred to, a light rolling accompanying the grouting. The advantages for this type of pavement are claimed to include the following:

1. A greater degree of compaction of the coarse aggregate and a considerable amount of additional strength in the completed pavement resulting from the mechanical or physical interlocking, brought about by the rolling, of the particles of the aggregate.

2. Greater uniformity in the surface presented to wear resulting from the more even arrangement of approximately the same sised pieces of aggregate in the wearing surface, and the avoidance of pockets greatly different in size of particles in the wearing surface of the aggregate. This is especially apparent where harrowing precedes the rolling and after the latter is completed and broken pieces are removed and replaced.

3. The distribution under the roller of the pieces of the aggregate in the wearing surface so as to present, as in macadam, a flat side against the wear rather than an edge or angle.

4. An advantage in the pavement, so built of a greater resistance to cross-breaking strains and consequently a greater supporting or distributing power over the foundation under excessively heavy loads.

5. A greater resistance to the forces producing expansion and contraction in the pavement thru the greater density and strength created in the pavement by this process, and consequently a less apparent effect of these forces.

6. An absence of the separation so often manifested in two-course pavements and exemplified by the riding of the upper course of one section over the surface of an adjacent section at an expansion joint.

There seems to be good ground for most, if not all, of the claims above enumerated, and the use of the Hassam pavement seems to be growing, in spite of the fact that a royalty of approximately 10 cents per sq yd is charged by the patentees for the use of their patent rights. Frequently this excess of first cost is offset by calling for a Hassam pavement of somewhat less thickness than would be specified for an ordinary concrete pavement, mixed and then deposited in place, under the probably correct assumption that a Hassam pavement 5 in in thickness, is of equal strength in strain supporting or distributing power to a 6-in pavement of ordinary mixed-concrete. The objections or difficulties with a grouted aggregate pavement are those incidental to all grouting work and include those of excess of water, segregation of mixed grout, and in getting the latter properly into its place in the mass.

The Specifications for the Hassam Pavement, as recommended by the Board of Consulting Engineers to the N. Y. Highway Comm. in 1913, are as follows:

"Hassam compressed concrete pavement shall consist of a layer of No. 4 stone, stone passing screens having openings between 2¼ and 3½ in in diameter, spread evenly to the required depth to conform to the established lines, grades and cross-sections, after rolling. This stone shall be thoroly compacted with a 10-ton roller until the voids are reduced to a minimum. The voids shall be filled with a 1:1 grout. The rolling shall be continued during the process of grouting. The grout shall be mixed in a Hassam grout mixer. A thin layer of dustless No. 1 broken stone or fine aggregate shall be spread over the entire surface and rolled until the grout flushes to the surface. Approved expansion joints shall be provided where required."

Criticism of the Above would seem to be fairly made by saying that they are too brief and not sufficiently comprehensive as to many important details. For instance, after the stone are spread, if they are thoroly harrowed before rolling, the uniformity in character of the surface will be much improved and consequently the uniformity of grouting. Then after rolling, if any pockets of broken pieces can be found, removed and replaced with fresh stone similar to those adjacent, the improvement in the results will be worth the effort. See also Art. 12, ROLLING.

Cement-Concrete Cubes. In 1909, J. Y. McClintock, County Engineer of Monroe County, New York, laid some experimental pavements in the effort to reduce the cost of suitable roadways in localities where broken stone and satisfactory gravel for macadam were expensive. A section of the experimental road crust was composed of concrete cubes made from the local gravel, which is reported as soft and not first-class concrete material. The cubes were laid by hand on an old macadam roadway with a cushion coat of fine gravel or sand. They were then rolled and the joints filled with a sandy loam. The traffic on the road is reported as heavy, mixed traffic. In the fall of the year, a great many agricultural engines with sharp lugs passed over the road. The cube surface is reported as wearing down rapidly, after giving a satisfactory surface with good footing in both wet and dry weather for 2 years, at the end of which time it disintegrated in large areas. The following conclusions have been drawn from this experiment.

The small cube form of pavement is flexible under frost action, and is therefore a suitable type over a macadam foundation in northern climates. The edge of the cube pavement can be successfully held with a macadam shoulder, making a gradual transition from the roadway surface to the earthy material and preventing the formation of ruts along the edge of the pavement. The local gravel concrete cubes will not support heavy traffic directly on their surface. In 1911, McClintock again experimented with concrete cubes made from a fair quality of gravel obtained from a pit adjacent to the road. The foundation course was 8 in of local gravel. The traffic over this section is reported as not large in volume but of heavy units, 6-ton trucks using it regularly. The surface of the cube pavements when completed was treated with bituminous materials. At the end of 1913, the road surface was reported in good condition, except a few incipient ruts in places assigned to the probable failure of the foundation under the truck traffic, and it is stated that "the experience with this road indicates, that where the local road material is limited to a good gravel, and where it is considered good policy to spend the road funds locally, or where the cubes are cheaper than imported stone macadam, the concrete cubes protected with a bituminous carpet make a satisfactory surface under a light volume of traffic." It is further stated that "concrete cubes at the present cost" can compete economically in only a few cases with macadam.

Oil-Cement-Concrete Pavements. With an idea of bringing about a reduction in the dustiness from concrete pavements and also to increase the imperviousness of the concrete, and hence to reduce the expansion or contraction movements in the mass, the addition of oil to the concrete mixture has been proposed and to some extent advocated. Experiments, however, have seemed to prove that a weakening in the strength of the con-

crete takes place from the addition of the oil, especially in the earlier part of its life, and that this weakness is appreciable in concrete used for pavements without a protecting carpet. The experiments with oil concrete cubes have particularly emphasized this conclusion. It is agreed that a reduction of the dustiness is secured by the use of the oil, but it may also be secured by the use of the oil over the surface of the pavement instead of in the mixture, and with less deleterious effects to the strength of the concrete. Any additional imperviousness of the concrete by the admixture of the oil is disputed by various experimenters. Many claim that the movements of the mass under expansion and contraction are reduced, but this is not at present substantiated.

Blome Granitoid Pavement. This pavement is essentially a two-course cement-concrete pavement, of which the surface course is made and placed as follows (25):

"After the concrete base has been placed, and before it has begun to set, there shall be immediately deposited thereon the granitoid blocking, which shall be 1¾ in thick. It will contain 1 part of Portland cement and 1½ parts of clean, crushed, monument granite or trap rock. This granite shall be screened, with all dust removed therefrom, utilizing the following composition of this material: 50% of the granite to be of what is known as ¼-in size, 30% of the ⅛-in size and 20% of the 1/16-in size. This proportion of sizes is essential, and must be kept absolutely accurate, as in this lies one of the essential requirements to produce proper results. This material is to be mixed with the cement thoroly, and after being wetted to a proper consistency and deposited on the concrete, shall be worked into brick shapes of approximately 4½ by 9 in, with rectangular surface similar to paving blocks. This will be done by special methods, and utilizing grooving apparatus as employed under the Blome Co.'s patents."

The Vibrolithic Pavement is an attempt to get a desirable increase in the density of ordinary mixed concrete. The following extracts from a description of the so-called Vibrolithic process will explain the idea:

"On a properly prepared subgrade there is placed 6 in of concrete. This concrete is so proportioned, cement to aggregate, as to give the maximum strength. Portland cement has a high coefficient of contraction, a factor to be avoided in concrete work. To add more cement to a good and sufficient mix is to add to the possibility of cracking. Enough cement must be used to secure the bond, but an excess will not answer the questions involved, nor will it increase the abrasive value of the surface. A concrete slab properly proportioned, mixed, watered and placed, will, by necessity, have more or less of its surface composed of unequal amounts of mortar or of stone. Certain small areas will be composed entirely of mortar, others of more stone. The wearing quality of the stone will vary from that of the mortar, thus producing an irregular wearing surface. To overcome this inherent defect in ordinary concrete, Vibrolithic specifications provide the following solution:

"Immediately upon placing, raking and smoothing to a true grade, there is spread upon the surface of the concrete, a coating of trap rock, sufficient to completely load the top inch or two of the mass. Narrow, flexible platforms are placed upon the stone and a vibrator is rolled over the platforms, until their bottom edges are brought to a true grade, and the surfacing stones perfectly imbedded in the slab. In this way the vibrator performs a double function, that of imbedding the stone, while densifying the mass.

"Vibrations are the most effective agents in compacting masses made up of members of angular form; for example, a barrel of tacks can not be compressed into a smaller volume, but a great reduction can be brought about by shaking, trembling, or vibrating the barrel. The same action will occur if the barrel contains an angular aggregate such as is used in concrete formations. This density is the most important requirement in placing concrete; first, to obtain a positive bearing of solid upon solid, and second, to assist chemical action and efficiency by getting the particles to be bound so closely related that crystal and colloidal bonds may be effective. It will be understood that the ties that bind, in concrete, are too small to be seen by the naked eye, hence the importance and value of density."

18. Bituminous Carpets

Various kinds of carpets may be applied to concrete as well as to other pavements, and varying thicknesses may be employed to meet any peculiar conditions. Bearing in mind that a carpet is a layer of appreciable thickness, the only reference that may be needed to the thin applications which are in the nature of varnishes, and similar in their action and effect to the use of varnishes on wooden floors for instance, is the caution to secure in using them such materials and methods of application as will result in a good union between the thin application of varnish and the concrete to which it is applied, and such quality of material as will give the most lasting results. Too thick an application of this character should not be attempted because of the shorter life to the coating thus usually secured. The cohesive qualities of such a varnished coat are usually much greater than its adhesion to the concrete, and consequently if a thick coat is attempted, its separation from the concrete is almost inevitable and it peels off under traffic, or shoves into irregular waves which become more and more apparent and objectionable as traffic continues on the road.

The Desirable Characteristics of This Carpet, both as to composition and thickness, depend largely on local conditions, but certain general principles may be laid down. In the first place, the bituminous material must have sufficient adhesive qualities and its application must be so made as to secure such an adhesion of the carpet to the concrete as will enable the carpet to perform its duties to the best of its ability. Sticky bituminous material is a prime necessity for a successful carpet and equally necessary, in order that the adhesive qualities of the bituminous material may be made the most of, is a clean surface of the concrete before applying the bituminous material. By clean surface of the concrete is meant not only freedom from dirt but also freedom from fine impalpable material usually accompanying concrete surfaces and produced by the disintegration under natural or other forces of the components of the concrete. Further it is most desirable that, so far as possible, the aggregate of the concrete be exposed to contact with the bituminous material in order that the bond between the two may be of the highest. The bond between the bituminous material and the cement mortar in the concrete is far less strong usually than the bond securable between the bituminous material and the coarser aggregate of the concrete.

Secondly, a desirable bituminous material should have the greatest possible permanence in its good qualities, that is, it should not be so susceptible to atmospheric and traffic conditions that it will under them quickly loose its adhesion or cohesion or elasticity.

Thirdly, the bituminous material must not be unduly susceptible to changes in temperature so that it will become soft and inclined to shift about in warm weather, nor become brittle and inclined to be objectionably friable in cold weather. The mineral material used in forming the carpet should be of the toughest quality possible so that it will withstand to the utmost the shocks and wear of traffic. The size of the particles desirable in any case will be influenced by the thickness of the carpet to be laid. Under ordinary conditions, it has been proved desirable to have the mineral particles uniformly as large as practicable for the required thickness, and as free as possible from finer material, the fine material necessary for the best formation of the carpet being readily secured from the disintegration of the coarse material in service. The best carpets seem to be made, other things

being equal, by the use of extremely clean and hard gravel of the proper size for the thickness of the carpet desired. Clean chips crushed from good trap rock frequently do nearly as well as the gravel, and fine sand makes the least desirable carpet. In fact a carpet of fine sand, in order to give even moderate satisfaction, must be of the thinnest possible construction and approach more nearly a varnish coat, or such a coat of paint sanded as is sometimes used to protect wood work.

Thickness of Carpets. Ordinarily, the carpets vary from about 1/8 to perhaps 1/2 in in thickness. Instances have been known where they have even reached 1 in in thickness, while the sheet-asphalt layers have sometimes been laid as thin as 1 1/2 in in thickness directly on the concrete base. These latter have shown a weakness to support more than a moderate amount of traffic. The consensus of opinion seems to be, that this weakness was due to the fact that the layer of sheet-asphalt mixture was attempted to be connected with the concrete foundation by a paint coat rather than thru the medium of the usual binder course. Again, the attempts to build *in situ* the carpet of a greater thickness than 1/2 in have almost always resulted unsatisfactorily, and the few instances of the 1 in carpets above referred to, which were mixed and placed almost identically in the same way as the sheet-asphalt pavements without the binder course, have not shown themselves able to stand satisfactorily more than a moderate amount of traffic. The conclusion therefore is that bituminous carpets are limited in their ability to give satisfactory service under traffic. Another conclusion generally reached is that attempts to build them *in situ* will be unsuccessful if they are not made less than 1/2 in in thickness, and that for carpets of greater thickness than this, especial care must be taken to provide the densest possible mixture for the carpet with the greatest practicable size to the largest particles in it, and at the same time the greatest possible adhesion or connection with its base either thru an efficient paint coat or thru such a means as the binder course usually provided in sheet-asphalt pavements.

The Destruction of the Adhesion of a Carpet to its base may come about in one or more of several ways. The bituminous material may be so changed under service as to lose adhesion and then the shifting tendencies of the traffic break the bond between the carpet and the base. The carpet may be so proportioned, as to lack stability and be susceptible to the shifting tendencies of the traffic. Its movement is then, under the traffic, merely a question of time. In all carpet foundations made of soft stone and particularly perhaps of concrete where the mortar forms a most friable material, the destruction of the bituminous carpet by scaling off in spots or shifting into waves, is most noticeable, and on such foundations, especially the concrete, especial care must be taken to provide such thickness and quality of the carpet as will protect to the utmost the concrete underneath from its natural tendency to become disintegrated under the shocks of traffic. These shocks produce a disintegration of the surface of the concrete beneath the carpet, and on which surface the stability of the carpet must depend by its adhesion to that surface. If this surface becomes disintegrated, the adhesion of the carpet to the mass of concrete is destroyed. This disintegration of the concrete underneath bituminous carpets is especially noticeable under hard tired and animal-drawn vehicles, particularly where the carpet itself lacks the thickness of body necessary for the absorption of the shocks coming on its surface to prevent the disintegration of the concrete surface beneath. Therefore, on concrete roads, it is desirable to provide the highest

quality of carpet securable in order that the disintegration of the concrete surface beneath may be prevented to the utmost. Another argument is now evident for the securing in the concrete itself the greatest possible area of the coarse aggregate in the surface with a minimum of the more friable material.

The Report of Com. VIII, 1914 Nat. Conf. Concrete Road Building (50i) included the following conclusions:

"Fundamentally, it would appear, that the surfacing of a concrete road implies a lack of confidence in the ability of concrete to withstand traffic. Many hold that the concrete of itself should bear the brunt and that the use of a protective medium is a confession that concrete has failed to justify the hopes held out for it. On the other hand are those who contend that a concrete pavement, no matter how well laid, will sooner or later crack and pit in spots, and, since these cracks and pits will be patched with bituminous material, it is wise to prevent this entirely by laying a carpet on the concrete surface. As to the materials and methods suitable for coverings there are equally wide differences of opinion. This is undoubtedly due to lack of sufficient experience. On one point, however, there is a well defined opinion that tar is more suitable for carpet coats than asphalt. On the other hand, there is some testimony that asphalt has given good results.

"It would appear, therefore, that investigations of bituminous surfaces for concrete roads should be divided into two parts:

1. Should concrete roads themselves bear the brunt of the traffic, or should some bituminous material be interposed to take the wear?

2. What has experience shown with reference to different materials and methods of application?

"In conclusion, one point can be safely emphasized. It admits of no discussion. The concrete pavement itself, even if it is to be covered by a bituminous coat, should be laid with as much care as if it were not to be protected. This applies to the preparation of the subgrade, and the proportioning, mixing, laying and curing of concrete."

Los Angeles, Cal. Practice (27b). "The concrete base for this road will be 24 ft in width and 8 in thick. It will be made of 1 : 2 : 4 concrete. This base will rest on a cushion of decomposed granite 5 in thick and 40 ft in width. Shoulders 8 ft wide will be built of decomposed granite on each side of the concrete base. The standard section for most of the Los Angeles County highways is a concrete base 20 ft in width and 5 in in thickness, with 5-ft shoulders. Transverse expansion joints across the full width of the concrete will be placed at 25-ft intervals.

"On the concrete is to be a bituminous carpet of a character common in California roadwork. The specification for the surfacing is worded as follows: After the concrete pavement has been constructed, all dust, mud, earth or foreign material of any kind which may have accumulated upon it shall be removed and the surface flushed with water. When it has become sufficiently hard and dry and in the opinion of the Road Commissioner is ready to receive it, asphaltic oil shall be applied in one application of approximately ½ gal to the sq yd. Directly after the oil has been applied stone screenings or sand shall be uniformly spread upon it in sufficient quantity to combine with the oil without leaving any excess screenings or sand on the finished road surface. The stone screenings or sand are to be spread in a direction parallel with the road and never crosswise. If necessary, from time to time, additional screenings or sand shall be spread, as the Road Commissioner may direct, to cover any oil which may come to the surface, until the final completion and acceptance of the work.

"It is estimated that this road will cost approximately $26 000 per mile. The County of Los Angeles is furnishing all material used in its construction."

MAINTENANCE

19. Methods of Maintenance

Considerable difficulty exists in making repairs to concrete in any form, the main difficulty being to secure a proper union between the new and the old concrete. A depression in a concrete pavement can only be repaired satisfactorily by cutting away sufficient old concrete in the depres-

sion so as to give an area of proper thickness with vertical edges, it being impossible to place new concrete on old with feathered edges, and to have these thin edges unite properly with the old concrete. When the area is cut out with vertical edges, it is impossible to prevent the formation of a perceptible joint in the circumference of the patch and all such joints in the rigid concrete are foci of weakness. The most successful repairs to a cement-concrete pavement are probably made by cutting out the area to be repaired and then filling the hole with bituminous concrete. In an uncarpeted concrete road, this produces unsightly spots and must be regarded as the beginning at least of finally carpeting or otherwise covering the whole of the concrete pavement and thus changing it really from a pavement to a foundation. The importance of these facts makes it wise to regard them carefully before going to much extra expense in construction for a particularly rich mixture for the concrete. In other words, if it is to be expected that, within a few years, the concrete pavement proposed to be laid is to be covered with a carpet of some kind, it will even be better to so draw the specifications for the concrete as to provide for the cheaper form of concrete foundation, and perhaps to allow it temporarily to be used as a roadway pavement, finally surfacing it as conditions make desirable, rather than to provide a much more expensive form of concrete pavement which will permit a longer life perhaps to the concrete, but which will inevitably and eventually require its relegation to the position of a foundation, where a much cheaper form of construction would be equally satisfactory.

The Joints of a Concrete Pavement generally begin to show the wear first and this is particularly true with those joints that accidentally occur in the form of cracks. The wear of the provided joints is intended to be guarded against by special forms of plates, but the marked difference between the wearing qualities of these plates under traffic and of the concrete adjacent to them seems to simply transfer the wear from the joint itself to the area just back of the plates. Where the provided joints are not protected by plates, and in the case of accidental joints or cracks, the edges of the joints or cracks quite quickly chip off and wear away, especially where there is much animal-drawn and hard tired traffic. The usual repair of such joints consists of cleaning them out as well as possible and filling them with bituminous cement.

The Edges of Concrete Pavements, especially where the roadway has been made too narrow to prevent many of the vehicles from turning off the roadway on to the shoulders, are particularly susceptible to disintegration under traffic. If the shoulder material is quite soft, a vehicle may run along for some distance, grinding on the edge of the concrete and wearing it severely before finally climbing back from the rut in the shoulder on to the concrete surface. Not only is the edge of the concrete pavement damaged in such cases, but the rut just outside of the concrete forms a collecting place for water which may accumulate there sufficiently to injure the foundation of the roadway and result in upheavals or cracks in the concrete slab. On all such roads, it is particularly desirable to construct and maintain the shoulders in such a manner as to prevent, as far as possible, the occurrence of the above described defects. For a discussion of maintenance of shoulders, see Art. 4.

Resurfacing an Old Cement-Concrete Road With New Concrete (66). "Grand River Road, Wayne County, Mich., was selected for this experiment as it would receive the severest kind of test, on account of the heavy mixed traffic which uses this high-

way and because the section selected was rough and uneven. This section of road was built in 1910, and is of 2-course construction. It is 6½ in thick, 16 ft wide, built on crowned subgrade. During the week of Aug. 17, 1912, 7444 vehicles passed a given point on this road, and during the week of Sept. 18, 1912, 7580 vehicles, by actual count, passed the same point, which is near where the road was resurfaced. To better accommodate increased traffic, the road was widened to 20 ft.

Method of Reconstruction. "All the Tarvia surfacing and filling used to cover cracks was removed. The cracks and holes were then filled with concrete to make an even surface 20 ft wide. The expansion joints, as steel protection plates were not used, were mostly worn down. Where the joint was spalled to a considerable extent, the old concrete was broken away sufficiently to give a bond for new concrete on both sides of the joint. Expansion felt was then placed and the whole surface brought up to an even grade. On the top layer of this base was placed a 3-in layer of 1:1½:2½ concrete using Marquette, Mich., trap rock, graded in size from ¼ to 1 in for the coarse aggregate, and washed and screened bank sand for the fine aggregate. The surface in no place is less than 3 in thick, reinforced with No. 26 triangular-mesh wire. No endeavor was made to bond the top course to the old road with a rigid bond. The surface of the old concrete was first sprinkled with water, after which a mixture of Tarvia A and Tarvia X was sprinkled on, hot, with an ordinary sprinkling can, immediately before placing the new wearing surface. The Tarvia, falling on the moist concrete, spread in a very thin layer and was immediately chilled, thus forming an even coat over the old surface. The expansion joints in this top course coincide exactly with the expansion joints in the bottom course. A piece of wood, 3 by 4 in, 20 ft long, was laid over the old joint, and the concrete deposited as tho no joint were to be made. Afterward this piece of wood was removed, and armor plates suspended from installing bars, with expansion felt, were set into place on the side forms, the felt of the new joint meeting the tar paper of the base joint.

"It is wise to add a word of caution that this resurfacing is regarded as wholly in the nature of an experiment which should be watched and studied, rather than generally advocated, until it has proven itself out."

20. Maintenance Cost Data

The Long Run Costs include the interest or sinking fund demands based on the first cost, the charges for maintenance or upkeep, the cost of repairs and allowances for depreciation or obsolescence. Trustworthy information from widely dispersed sources concerning the detailed costs of upkeep and repairs on concrete pavements for a sufficiently long period has not yet been published. In the few cases, where detailed information has seemed to be accurately given, the statements have been lacking in other vital respects such as concerning the amount of use to which the particular road has been subjected. Manifestly, under such conditions, conclusions of value are impossible. Inskeep (40) states that the cost of repairs to about 7300 sq yds of concrete pavement built around a public square in Bellefontaine, Ohio, in 1893 and 1894, "under the existing conditions * * * in he last seven years has been $173.88." Much information of value in this connection is lacking, especially as regards the amount of traffic using the roadway. See (50g). Tentative deductions may sometimes be made, which will indicate possibilities, tho generally even these require assumptions from more or less controversial starting points and these assumptions may vitiate the results. For publications of figures on cost of maintenance of concrete roads, see (56) and (57).

Connecticut Method of Maintenance (64). "A straight well-made joint can be much more easily taken care of than any ragged crack which might result if no joint were used, or if the distance between were lengthened. All joints are treated with tar during the hot weather of the first summer after the completion of the work, and as often thereafter as necessary, but only in warm weather. A tar kettle of about 150 gal capacity, a pouring pot of the type use for pouring bituminous filler for brick pave-

ments, a wire push broom and a couple of laborers, comprise the outfit necessary to properly take care of this work. The joint is first brushed clean, then filled with tar and covered lightly with sand or stone chips, which have previously been distributed along the road. The cost of this work varies with the conditions of the joints and price of labor. Longitudinal cracks are the most frequent and annoying results of forces exerted after the work has been completed. These occurred more frequently on the earlier contracts which were not reinforced, and also on those which were so situated that the frost could effect an entrance under the road from the sides, lifting each edge and causing cracks to appear when the surface returned to its normal position. These cracks have been treated in exactly the same manner as the joints.

"Practically all of the work on the surface of these roads is performed in the same manner as outlined for tarring joints, and with the use of the same materials. A medium heavy tar which required heating is used. Any tar which will conform to the following specifications will be found satisfactory. Specific gravity at 21° C (70° F), 1.20 to 1.30. Free carbon, 10 to 25%. Distillation: Total to 77° C (170° F), not over 5%; total to 157° C (315° F), not over 30%. Specific gravity of entire distillation at 15.5° C (60° F), 1.033 to 1.038. Melting point of residue, 46° to 71° C (115° to 160° F).

"The size of the sand or fine stone used with the tar should depend on the size of the defect being treated, and should be clean. If defects are treated as soon as they appear, practically no cover will be used larger than torpedo sand.

"Actual COSTS of the maintenance for the various contracts have been kept for a period of 2 years, and the results are very satisfactory. Twenty-five miles of road have been used in obtaining the figures given care being used to include those carrying all classes of traffic from the heaviest to the lightest. The actual cost of all tar work applied to the concrete surface has been $38.63 per mile per year, or about 0.4 cents per sq yd of travelled path per year. The cost of shoulder work and drainage has been $28 per mile per year, or 0.3 cents per sq yd per year."

Maintenance Costs in Illinois (52b). "The average cost of maintenance and upkeep of concrete paved streets and roads in Illinois in 1915 was 0.4 cents per sq yd. This figure is the average for 75.3 miles of state aid highway, aggregating 555 013 sq yd of paved surface. The average cost of maintenance for 6.06 miles, 56 554 sq yd of pavement, on township aid concrete roads in 1915 was 0.81 cents per sq yd."

Table IX.—Maintenance Cost of Concrete Pavements in Illinois in 1915

County	Date of Acceptance	Labor	Material	Transportation	Equipment	Supervision and Overhead	Cost of Maintenance	Cost per Sq Yd
Adams	1915	$23.65	$14.86	$3.65	$5.35	$5.76	$53.27	$0.0059
Boone	1915	6.00	4.87	2.59	3.90	2.11	19.47	0.0038
Cass	1914	9.75	18.28	9.61	3.56	5.00	46.20	0.0107
Clark	1915	8.00	11.71	8.54	2.80	3.82	34.87	0.0062
Clay	1915	11.10	4.08	6.27	2.08	2.86	26.39	0.0068
Cook	1914	3.00	6.66	1.07	1.90	1.53	14.16	0.0027
Cook	1914	8.00	19.05	2.16	10.60	4.83	44.64	0.0031
Menard	1915	21.60	2.70	4.64	1.90	3.74	34.58	0.0135
Moultrie	1915	8.50	2.34	8.97	3.36	2.83	26.00	0.0033
Whiteside	1915	22.50	10.93	3.87	....	4.50	41.80	0.0121
Will	1914	44.00	11.73	9.70	6.90	8.78	81.11	0.0074
Williamson	1915	25.46	14.83	5.33	3.60	5.97	55.19	0.0079
Woodford	1915	18.00	13.27	7.92	1.92	4.99	46.10	0.0057

Table X.—Maintenance Costs of Concrete Pavements in Milwaukee County, Wis. (46)

Year Built	Miles	Square Yards	Concrete Maintenance in 1914		Concrete Maintenance in 1915		Concrete Maintenance in 1916		Average Yearly Cost per Mile
			Cost Per Mile	Cost Per Yard	Cost Per Mile	Cost Per Yard	Cost Per Mile	Cost Per Yard	
1912.......	1 350	14 000	$857.89	$.08270	$1225.52	$.11810	$240.81	$.02330	$782.16
1912.......	2.500	29 482	165.02	.01400	184.22	.01560	324.79	.02750	224.67
1913.......	0.190	2 000	842.10	.08000	510.73	.04850	100.00	.00950	776.315
1913.......	21.976	226 777	50.55	.00489	25.33	.00245	42.85	.00414	39.56
1914.......	23.845	250 363	20.35	.00179	25.72	.00245	34.95	.00313	39.71
1915.......	36.360	400 861	......	......	....	......	30.83	.00279	30.83

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SECTION 22

STREET CLEANING, COLLECTION AND DISPOSAL OF WASTE, SNOW REMOVAL

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STREET CLEANING

1. General Considerations Relative to Street Cleaning

Engineering and Economic Problem. Street cleaning is one of the last municipal engineering problems to be placed under the control of engineers, and, in fact, it is in only a very few localities (1918) that this very important municipal service is under engineering control, as it is still being used in many localities for the purposes of political patronage. The principal factors in connection with this problem so far as cleaning the streets themselves is concerned are engineering and economic considerations. Engineering considerations embrace sanitary conditions, character and extent of traffic, character and condition of the pavements, social and local condi-

tions, and equipment and methods of cleaning, while the economic consideration resolves itself into a question of financial policy in each community. In other words, in this work as well as in paving work and all other public service work each community must determine upon its own policy. This does not mean, however, that sufficient cleaning should not be performed to comply with the sanitary requirements. It is for the engineer to determine upon the methods and the extent of the cleaning it would be desirable to do in order to keep the streets in as near as is possible an ideal condition from the standpoint of cleanliness, but, as in other undertakings, the prohibitive cost often makes it impracticable to attain the ideal.

Classification of Methods of Street Cleaning. In general two kinds of street cleaning are recognized, namely, preventive street cleaning and corrective street cleaning. Preventive street cleaning may be stated to consist principally in the institution and adoption of means of preventing dirt or waste materials being placed or scattered upon the highways; while corrective street cleaning consists in the collection and removal of such dirt or waste material as has found its way onto the highways. The responsibility for the performance of preventive and corrective street cleaning, it is recognized, must rest to a great extent, respectively with the general public, the municipal street cleaning organization and the police department. The police department is the only agency thru which the enforcement of the preventive street cleaning laws can be carried out, and the enforcement of these laws is essential in order that a solution of the street cleaning problem may be effected.

2. Preventive Street Cleaning

General Considerations. Tho the results accruing from the activities included under preventive street cleaning cannot be definitely expressed in figures, as in the case of corrective street cleaning, it is, however, just as important a function of street cleaning as the performance of the corrective work itself and every effort exerted in this direction is fully justified. For obvious reasons, it is absolutely certain that preventive methods are destined to enter more and more into the street cleaning problem in every municipality. In formulating a definite policy along which preventive street cleaning work should be conducted, it is necessary first to determine the contributing causes to unclean streets, in order that it may be possible to control or eliminate them thru carefulness, thoughtfulness, or observance of the laws on the part of the general public.

Principal Causes of Unclean Streets.

1. The neglect of occupants of homes, stores and other buildings to properly dispose of sweepings and refuse from their premises and sidewalks, and to refrain from sweeping or placing such materials onto the highways, especially after they have been cleaned.

2. The failure to use tight metal or other suitable receptacles for ashes, rubbish and garbage; the failure to allow a clear space of several inches between the tops of the receptacles and the top of the contained materials in order to prevent their being blown or spilled upon the highways; and the lack of care in the manner of storing receptacles while awaiting collection, so as to prevent their being overturned by passing traffic.

3. The illegal and careless distribution on the highways or to homes and other buildings of advertising literature in the form of circulars, handbills, cards and fake newspapers.

4. The neglect of pedestrians to properly dispose of discarded newspapers, cardboard boxes, paper, fruit peelings and refuse.

5. The non-separation by occupants of homes and other buildings, of rubbish from ashes, placed on the highways for collection by the municipal collectors.

6. The interference with and scattering of the contents of receptacles awaiting collection, by itinerant scavengers.

7. The overloading or improper loading of vehicles hauling dirt or other fragmentary materials, or the use of defective or unsuitable conveyances; and the permission of vehicles entering upon the highways with the wheels carrying an accumulation of dirt or mud.

8. The illegal and careless packing, unpacking or storage of materials on the highways.

Enforcement of Preventive Measures. In order to eliminate or reduce to a minimum these contributing causes, every effort should be made to educate the general public in their individual duties, and to the necessity, advantages and possibilities of preventive street cleaning. Insofar as it is practicable and possible for the city to do so, equipment and helpful suggestions and instructions should also be furnished.

The Principal Specific Means for Controlling These Causes Employed by the Philadelphia Bureau of Highways, 1912 to 1917, may be enumerated as follows:

1. Continuous educational work consisting of extensive newspaper publicity, public neighborhood lectures; and, where practicable or necessary, individual personal advice or instruction from the inspectors.

2. The inauguration of an intensive educational preventive Clean Streets Campaign under the joint auspices of the City of Philadelphia, The Philadelphia Chamber of Commerce, the United Business Men's Association, the Poor Richard (Advertising) Club, the Philadelphia County Medical Society, the Child Federation, the Emergency Aid Association and the Civic Club of Philadelphia, for the purpose of enlisting the aid of every possible coöperating agency.

3. The personal serving by police, upon the responsible occupant of every home and other building thruout the City, of cards enumerating in the form of Don'ts the most generally prevailing violations of the laws which contribute toward unclean streets, together with abstracts of the laws and the penalties for their violation; and the exhibition of displayed placards containing this data in the trolley cars, store windows, railway stations and other conspicuous places thruout the City.

4. The assignment of specially trained forces of inspectors to personally appeal to occupants of homes and other buildings to coöperate by obeying the existing laws.

5. The sending of legal notification letters to persons or agencies who persisted after warning, in violating the laws in matters contributing to unclean streets, and prosecuting the offender in instances where further violations are noted.

6. The assignment of an assistant engineer to enlist and encourage the coöperation of housekeepers and school children by giving informal talks at schools and before women's organizations.

7. The furnishing and maintenance of attractive rubbish receptacles in prominent locations on the highways thruout the City; and the encouragement of large business interests and civic, and neighborhood business men's and improvement associations to assist in the extension of this work.

8. The general enforcement of the municipal ordinance requiring the separation of ashes and rubbish.

9. The enforcement of the law requiring occupants of homes and other buildings to provide approved types of rubbish and garbage receptacles, and to properly store them while awaiting collection.

10. The control, thru the coöperation of the police department, of itinerant scavengers operating in violation of the law, with a view to their ultimate elimination.

11. The institution of an annual Clean-Up Week, which insures the periodic and satisfactory disposal of a very considerable quantity of rubbish, a proportion of which would otherwise ultimately find its way onto the highways.

12. A closer attention to the character and suitability of the vehicles employed and the manner of loading and transporting dirt and other fragmentary materials over the highways, and the assignment of an inspector where necessary to inspect such vehicles prior to permitting them to enter upon the highways.

Publicity. In connection with the preventive street cleaning propaganda, it is considered that publicity of the kind that will reach and favorably impress the entire body of citizens is absolutely essential to the attainment of results. In this connection, publicity is obtained thru the following mediums:

NEWSPAPERS. New items in both daily newspapers and weekly neighborhood periodicals relating to the day to day activities of the bureau of highways in connection with the preventive street cleaning work and also stories of the experiences and conditions discovered by the educational inspection force.

MEETINGS. Public meetings held under either the specific or joint auspices of the municipal government, civic and trade bodies and neighborhood business men's and improvement associations.

LITERATURE. Educational notice cards and pamphlets describing the various ways in which householders and citizens in general may coöperate; placards for store window, trolley car, railway station and bulletin board display and poster stamps for attachment to correspondence and bills sent to the public by the municipal government, public utilities and business houses.

Clean-Up Week. The main purpose in conducting an annual municipal clean-up week campaign is to provide healthier and safer living conditions for the people in general by removing accumulated trash and rubbish from the interior of buildings and from all open areas. It is a demonstrated fact that carelessness in the storage of rubbish in cellars, attics and closets is responsible for a considerable portion of fire losses, while it has also been shown that unclean surroundings breed disease germs, which are in turn transmitted to human beings thru various agencies. To clean up regularly by collecting and disposing of all useless trash gives to a community an orderly and well-regulated appearance and eliminates much rubbish that would in all probability contribute at some later time to the littering of the highways. It stimulates the citizens, whether rich or poor, to concentrated effort at stated times and thereby develops instinctively the habit of cleanliness and orderliness. To promote such a campaign successfully requires the active coöperation of every individual in the municipality. Obviously, the necessary information covering the general plan of procedure must first be given to each man, woman and child and in a form to be assimilated by each. It must also be repeated as often as necessary in order that each one may be impressed with his or her personal responsibility in the matter. Publicity, therefore, should be the key-note of a clean-up campaign. The best results will be obtained thru a joint working committee of city officials and members of the local Chamber of Commerce or Board of Trade, their principal objective being to start the campaign and keep it in motion by using every available channel of publication. The newspapers are possibly the most efficient mediums of publicity and by publishing daily news articles, advertising wares of tradesmen and in giving ample advance notice of the coming event, keep the idea constantly in the public eye. The assistance of the local public service corporations in the preliminaries of the campaign by placing placards containing information in trolley cars and stations and by using poster stamps on bill heads, statements and outgoing mail is invaluable; business men's and civic organizations thru conducting neighborhood meetings and distributing literature gain the attention of the people living in their immediate vicinities; children in public and private schools thru a course of instruction as to the part they may take in cleaning up, which also provides for the awarding of prizes for the best appearing yards, alleys, etc, are encouraged to individual effort; inspection of divided areas of the municipality by Boy Scouts and other junior organizations in order to locate vacant lots, open areas, yards, alleys, etc, requiring the attention of the owners is a most important feature. The campaign should be officially begun by the mayor issuing a proclamation just prior to the opening of clean-up week requesting all citizens to give their best efforts to one week of cleaning up and beautifying.

OPERATIONS DURING CLEAN-UP WEEK. The preliminary or educational features of the campaign having been thoroly coördinated and properly concluded, the actual work of collecting and disposing of the waste materials set out, requires rapid and efficient handling on the part of the organization in charge. In a large municipality, particu-

larly during the first and second campaigns, an increase of not less than 25% in the number of extra teams employed over the number usually required to collect rubbish will be necessary with a corresponding increase in the number of helpers, in order to complete each day's work according to the department schedule. As the disarrangement of the schedule of an ash and rubbish collection and street cleaning department is serious, every effort should be made to complete the clean-up campaign within the prescribed time. This, of course, requires judgment in the employment of additional equipment and helpers for which no set rule can be formulated. It will depend entirely upon the arrangement of the daily schedules, ample provision being made beforehand for those districts in which the normal weekly collections are heaviest.

Results Obtained. The best results are not to be looked for during the first campaign as the public in the beginning may be more or less apathetic and incredulous but they will be quickly converted to the value of the idea once the impression is gained that it means safety against disease and fire. Thereafter, cleaning-up gradually becomes habitual with the real purpose of the movement, which is to encourage continuous or year-round cleaning constantly progressing. The successful results of such a campaign may be summarized briefly as follows:

1. Reduction in fire loss and elimination of fire hazards; the lessening of the number of house flies and mosquitoes during the summer months.

2. The improvement of sanitary conditions and the elimination of objectionable conditions on vacant lots; cleaner houses, yards and alleys, safer and more attractive houses and surroundings.

3. The training of school children in the principle of the cleaning up idea; fire prevention, cleaner streets, development of school and neighborhood gardens, etc.

4. A higher standard of civic pride in the people for their city.

Philadelphia Clean-Up Campaigns. This procedure has been followed in Philadelphia most successfully from 1913 to 1916, inclusive, the administration of the campaign and the collection and removal work being under the auspices of the Bureau of Highways and Street Cleaning, which is in responsible charge of the collection and disposal of ashes and rubbish. Tho the other branches of the municipal government, such as the Departments of Health, Police and Fire, should coöperate in the campaign, yet the department having regular charge of rubbish collection thruout the year is the logical organization to supervise the clean-up week campaign. During the Philadelphia campaigns of 1913 and 1914, the accumulations were noticeable for the presence of heavy and cumbersome articles, such as furniture, bed springs and mattresses, etc. In 1915 and 1916, minor household waste and refuse, such as discarded tin and iron ware, kitchen utensils, rags and carpets, broken china ware, glass and bottles, predominated. The difference in the character of materials collected and transported to the City dumps during these years represents the improvement in general conditions within homes and may be regarded as a typical experience, which any municipality about to conduct a clean-up campaign may expect. In 4 years, rubbish and waste to the amount of 388 000 cu yd was collected and disposed of during Clean-Up Week at a total cost to the City of $61 400.72, or an average of 15.8 cents per cu yd, or $0.0361 per capita. During each campaign, an average of 1500 extra teams and 225 extra helpers were employed in the work of collecting and transporting waste to the reclamation stations and other rubbish, not of a salvable nature, to the dumps.

Highway Rubbish Receptacles. In order to encourage pedestrians to properly dispose of discarded newspapers, card board boxes, fruit skins and other refuse and to provide convenient facilities therefor, specially designed portable highway rubbish receptacles should be placed at highway intersections and in front of schools, factories, railway stations and at other conspicuous locations on the highways, thruout the city and also on the streets occupied by curb produce markets. These receptacles are durably manufactured of sheet and strap iron and are cylindrical in shape with half-hooded top and a drained and ventilated bottom. They have a capacity of 5.4 cu ft. Eight stiffening staves on the outer side of the receptacle extend from top to bottom at equi-distant points, and two handles are placed at the middle on opposite sides of the receptacles. The receptacles may be painted grass green and contain in white, the wording "For Waste Paper and Refuse. Help Keep the Streets Clean." A number of the public utilities, large business houses and neighborhood business men's and improvement associations may provide, at private expense, a number of

similar receptacles for use in their vicinities. The contents of all highway rubbish receptacles should be collected daily by the rubbish collection contractors.

3. Corrective Street Cleaning

Frequency Classifications of Street Cleaning. In general, frequency and sequence of street cleaning is based upon considerations of economy and actual necessity as governed by sanitary considerations, the character and condition of the pavement, the volume and character of the traffic, the locality and the convenience of the traveling public.

In Philadelphia, from 1912 to 1917 while the author was Chief of the Bureau of Highways and Street Cleaning, the following system of classification was utilized, each class to be cleaned according to a definite prearranged schedule.

City Streets:

Class A. Cleaned every day, meaning each day except Sun. or the legal holidays as indicated in the specifications.

Class B. Cleaned every second day, meaning Mon., Wed. and Fri.; or, Tues., Thur. and Sat. of each week.

Class C. Cleaned every third day, meaning Mon. and Thurs.; or, Tues. and Fri.; or, Wed. and Sat.; or, Mon. and Fri.; or, Tues. and Sat. of each week.

Suburban and Country Roads.

Class D. Cleaned once a week on a definite day.

Class E. Cleaned twice a month.

Class F. Cleaned once a month.

Class G. Cleaned once in 6 weeks.

Class H. Cleaned once in 2 months.

Methods of Street Cleaning in General Use. In determining upon the method of cleaning to be employed upon any specific highway, the first consideration is that of the character and condition of the pavement to be cleaned, but, in addition to this, sanitary, traffic, public convenience and economic considerations play an important part. The general methods at present employed in the cleaning of pavements and roads are as follows: (1) Pick-up by blockmen; (2) machine broom preceded by sprinkling; (3) squeegee preceded by sprinkling; (4) high pressure machine flushing; (5) hand brooming by gangmen; (6) hose flushing. Tho in the organization of the machine cleaning practice an effort has been made to standardize the methods of cleaning with respect to character of pavement and other governing conditions, it is nevertheless quite impossible to adhere strictly to the standards determined upon during freezing weather which frequently necessitates radical departures. Squeegee and flusher cleaning and sprinkling is discontinued when a low temperature makes their use undesirable. When, however, on account of weather or temperature conditions, squeegee or flusher cleaning or sprinkling must be discontinued and machine brooms cannot be operated, the streets are cleaned by supplementing the regular force of blockmen with additional gangmen and the regular force of laborers, alley and inlet men.

Machine Broom Cleaning. Machine broom cleaning is used principally on stone and vitrified block or brick pavements, and also on sheet-asphalt and wood block pavements having a rough or irregular surface. It is practically impossible to have absolutely clean streets unless they are well paved. The older types of stone block and brick pavements constructed without grouted joints are difficult to clean, as dirt lodges in the joints, especially if they are wide. Pavements not laid on a concrete base will, in all probability, develop numerous depressions due to settlement under

the severe requirements of traffic. These depressions, of course, collect dirt, much of which cannot be removed by the machine broom and has to be broomed out by hand.

Method. The machine broom gang unit should consist of a horse-drawn sprinkler followed by a battery of 1, 2 or 3 horse-drawn machine brooms, the number depending upon the width of the street to be cleaned, 1 foreman and from 4 to 8 gangmen should follow each machine broom, depending upon the character and condition of the pavement and the quantity of dirt to be removed, and from 4 to 8 carts with drivers and helpers if necessary. All laborers should be equipped with push brooms. In working the machine broom gang, it should be so arranged that the various operations will be performed closely following one another. The sprinkler should precede the machine brooms by about 200 ft. The output of water from the sprinkler should be so regulated that just enough is used to loosen the dirt and to prevent the formation of dust during the sweeping operations. If an excess of water is used, the dirt becomes pasty with the result that the machine broom cannot properly clean the pavement. The machine brooms, in battery formation, should follow 200 ft in the rear of the sprinkler, and the dirt should be swept from the center of the roadway toward the gutters. The foremost machine broom should progress along the center line of the roadway, closely followed by the other brooms, each of which should overlap the swath of the preceding broom to pick up the windrow of dirt collected by that machine, thus finally conveying it to the gutter. Tho the brooms in the machines are usually from 6½ to 8 ft in length, yet the actual width of the cleaning swath will not exceed between 5 to 7 ft, due to the angle at which the broom is set in the machine and to the fact that where more than one swath is necessary to clean a roadway, each successive swath must overlap the preceding one. If the machine brooms are in good condition and properly adjusted only one operation will be necessary to clean a pavement satisfactorily but where the pavement is in bad condition or the roadway is unusually dirty, it may be necessary to go over the roadway two or more times or resort to flusher cleaning. If the condition of the roadway with respect to dirt is such that the pavement cannot be satisfactorily cleaned in one operation, it is advisable that the street should be scheduled for more frequent cleaning. All areas or depressions which the machine brooms cannot properly clean should be carefully spot cleaned by gangmen. The gangmen should follow close behind the machine brooms, and in no case more than 400 ft, brooming the dirt into piles in the gutters at intervals of about 25 ft. The dirt collection vehicles should closely follow the gangmen and the piled dirt should be immediately loaded into the vehicles and hauled to the dump. The important reason for keeping the gangmen and dirt collection vehicles working close behind the machine brooms is to prevent the dirt from being scattered by traffic and wind. If too great an interval is allowed between the brooms and the gangmen, the dirt will become dry, especially in hot weather, and when the gangmen broom the dirt into piles, considerable dust will be raised. Dust is not only unsanitary, but also is very annoying to passing pedestrians and the occupants of near by buildings, and, therefore, every precaution should be taken to eliminate this nuisance. The dirt should be piled in the gutters where neither the dirt nor the vehicles collecting it are in the way of moving traffic. After the dirt has been loaded into the collection vehicles any dirt left on the site of the pile should be carefully broomed with a small handbroom into a shovel and the site left perfectly

clean. A properly adjusted and equipped machine broom will satisfactorily clean an average of 90 000 sq yd of pavement per day of 10 working hr. This area will, of course, vary somewhat, depending upon local conditions, such as the character and condition of the pavement and the amount of traffic.

Squeegee Machine Cleaning. Squeegee machine cleaning is confined exclusively to sheet-asphalt, bituminous and wood block and brick pavements having a smooth surface. If these pavements are not in good condition, or contain depressions or pot-holes, satisfactory results cannot be obtained by using this type of equipment. Another point to be considered is that squeegees will not satisfactorily clean a pavement that is very dirty or one that is not cleaned at frequent intervals. Squeegee cleaning is intended primarily for roadways where the dirt to be removed is comparatively light, either because they are patrolled by blockmen or the traffic does not produce an excessive quantity of dirt.

Method. The squeegee gang unit should consist of a horse-drawn sprinkler followed by a battery of 1, 2 or 3 horse-drawn squeegee machines, the number depending upon the width of the roadway to be cleaned, 1 foreman and 3 gangmen to each squeegee machine and 2 or more dirt collection vehicles with drivers. All gangmen should be equipped with push brooms. In operating, the squeegee machine gang should be so arranged that the various parts of the gang will work together as closely as practicable. The sprinkler should precede the squeegee machines by about 200 yd. This interval of space is sufficient to permit the water to saturate and loosen up the dirt on the pavement without giving it time to evaporate. Squeegee machine cleaning requires the application of considerable water to the pavement surface and sufficiently in advance of the rubber brooming operation to loosen the dirt thoroly. The squeegee machines, in battery formation, should follow 200 yd in the rear of the sprinkler, and the dirt should be broomed from the center of the roadway toward the gutters. The foremost squeegee machine should progress along the center line of the roadway, closely followed by the other squeegee machines, each of which should sufficiently overlap the swath of the preceding machine to engage the windrow of dirt collected by that machine thus finally conveying it to the gutter. Tho the rubber brooms in the squeegee machines are usually from 7 to 7½ ft in length, yet the actual width of the cleaning swath will not exceed 6 ft, due to the angle at which the broom is set in the machine and to the fact that where more than one swath is necessary to clean a roadway, each successive swath must overlap the preceding one. In every case a sufficient number of swaths should be taken to cover completely the entire width of the pavement and to convey the windrows close to the curbs. If the squeegee machines are in good condition and properly adjusted only one operation will be necessary to clean a pavement satisfactorily but where the pavement is unusually dirty, it may be necessary to go over the roadway two or more times. All depressions which the squeegee machine cannot properly clean should be carefully spot cleaned by gangmen. The method of procedure for the removal of dirt should be identical with the requirements outlined in connection with machine broom cleaning. A properly adjusted and equipped squeegee machine will satisfactorily clean an average of 75 000 sq yd of pavement per day of 10 working hr. This area will, of course, vary somewhat depending upon local conditions.

High-Pressure Flusher Machine Cleaning. High-pressure flusher cleaning may be satisfactorily used on practically all types of pavements. In some cases, it supplements the other methods of regularly scheduled ma-

chine cleaning. It is very effective on all kinds of stone and vitrified block or brick pavements and on sheet-asphalt and wood block pavements where the surface is so worn or irregular that the depressions would hold dirt that could not be dislodged by either squeegee or machine broom cleaning. The principle upon which the high-pressure flusher method of cleaning is based is that of loosening the dirt from the pavement surface by jets of water under pressure and then flushing the dirt to the gutters.

Method. The flusher cleaning gang unit should consist of one or more automobile high-pressure flushers with a driver and 1 operator each, 1 foreman, from 4 to 6 gangmen and from 1 to 3 dirt collection vehicles and drivers. The correct position for the flusher nozzles is the most important consideration in this kind of cleaning. They should be set approximately 18 in above the pavement surface and set at such angles as will insure a thoro cleaning of a maximum width of pavement. The front nozzle streams should form windrows in such positions that the rear nozzle streams can pick up and throw them toward the curbs. The streams from the two front nozzles should cross, but not cut thru each other, as this will diminish the force with which the water strikes the pavement. Each nozzle should have an effective swath of 8 ft in width on smooth pavements and of 6 ft in width on irregular or block pavements. After the correct positions for the nozzles have been finally determined, they should be permanently locked or set in those positions; otherwise, they will be constantly tampered with by the foremen and others, and very poor cleaning will result. The pressure under which the water is ejected from the nozzles also should be given careful study. The usual pressure is 40 lb per sq in. When the flusher is operated on narrow roadways that can be cleaned by one swath, or on other roadways where the pavement is very dirty or is of an open joint block type, the rate of progress should not exceed 3 to 4 miles per hr. On smooth-surfaced or comparatively clean pavements the speed may be relatively increased, but should not in any instance exceed 8 miles per hr. The general tendency on the part of flusher operators is to go too fast. This will result in poor cleaning especially if the pavement is comparatively dirty. The matter of proper speeds for flushers should be given careful consideration and standard regulations adopted to suit the several varying conditions. On streets requiring more than one swath to clean them, the first swath should be taken along the center line of the street and a sufficient number of successive overlapping swaths made to carry the windrows to the curbs. When operated in conjunction with squeegees, the flusher should progress along the center of the roadway with the squeegees following in battery formation. Enough gangmen should closely follow each flusher or battery to broom the dirt along the gutters to the nearest sewer inlets, where the dirt is piled and the water allowed to drain into the sewer. The flusher may be operated either up or down grade, but the gangmen must always work down-grade. The dirt collection vehicles should closely follow the gangmen and load and haul the dirt to the dump. All dirt sites should be left clean by brooming up any remaining dirt. A high pressure flusher should satisfactorily clean 100 000 sq yd of pavement in a day of 10 working hr. The percentage of time that the machine will consume in loading water will vary greatly with the pressure at the hydrant.

Hose Flushing. The hose flushing method of street cleaning can be made use of readily by a city of any size, as it has the great advantage of not requiring an expensive equipment. This method is of special value for quick and thoro clean-up work and for removing entirely the dust from

the surface of city streets. As a rule, however, hose flushing in the larger cities supplements rather than replaces machine cleaning, except on roadways too narrow to permit the use of the machine cleaning equipment. The principal disadvantage of hose flushing is that of the waste of water unless the work is closely supervised. In order to accomplish effective results with hose flushing, the hose stream should be kept in motion at all times and directed downward on the surface of the pavement within a radius of 40 ft of the nozzle man. If the hose stream is directed at one spot more than 20 or 30 sec, this generally results in a waste of water and time. In no case should the hose stream be raised upward into the air as this results in the pavement being simply sprinkled rather than washed.

Methods. There are two general methods of hose flushing, which may be described respectively as the large gang method and the small gang method.

In the large gang method, the flushing gang unit should consist of 1 foreman and 8 laborers, equipped with not less than 150 ft of 2 or 2½-in hose, a portable hose reel, push brooms and, if necessary, hoes and shovels. The hose should be provided with an elliptical nozzle, made purposely for this class of work. The method of operating this gang is, first, to have the pavement thoroly wetted; any pavement area that cannot be reached by the hose stream should be wetted by brooming water over it, the idea being to moisten and loosen the dirt. The broom men then form in battery and proceed down grade, while the hose men play a stream of water in front of them. The windrows from the first and other brooms are engaged successively by the brooms following and are carried finally to the gutters. If necessary, in order to produce satisfactory results, this operation should be repeated two or more times. When conditions warrant it, 2 or more men also may be assigned to spot flushing and cleaning. A hose flushing gang should clean, in a satisfactory manner, 30 000 to 35 000 sq yd of pavement in a day of 10 working hr.

In the small gang method of hose flushing, the gang unit should consist of 2 men, and all the dirt must be removed by the water. The flushing is done down grade and the mud wave is driven toward the gutters.

Report on Investigation of Hose Flushing by Parlin (32). "Until 1914 New York City had been using ordinary 2½-in fire hose and 1¼-in nozzles. The equipment was carried on the regular sweeper's can carrier or dragged over the pavement from place to place by 2 or 3 sweepers. This equipment was not only ill-adapted to the work but heavy, unsightly and liable to cause rapid deterioration of the hose on account of the sharp bends which were necessary.

"Investigations made by Wagner, an engineer from the Dept. of Water Supply, Gas and Electricity, New York City, indicated that:

1. An average of 1800 gal of water was being used per 1000 sq yd of pavement cleaned.
2. Other cities were using smaller sizes of hose and nozzles with apparent satisfaction.
3. Experiments made with 1½-in and 2-in hose and small nozzles indicated that the work of cleaning could be properly done with from 370 to 660 gal per 1000 sq yd on asphalt.

"As a result it was recommended by the engineer that the department of street cleaning adopt 1½-in equipment, which would be much easier to handle and save more than two-thirds of the water then used. The recommendation did not agree with the experience of the officers of the department of street cleaning, several of whom had tried the small equipment. The claim was almost universally made among these men that the use of so small a hose and nozzle would make it impossible for men to cover the ground they were then covering and would make the work very expensive. Thus developed two points of view, one looking primarily at the waste of water and the other at the waste of time. Between these it became necessary to run a second set of experiments to determine the size of equipment which would be cheapest to

operate from the taxpayers' or general city view-point, taking into account both the cost of labor and the cost of water. This second set of experiments, conducted alternately upon 1½-in and 2-in equipment, resulted in the selection of the 2-in equipment as standard for the city. Attention was at the same time called to the possibility of using the smaller size with equally good results wherever the pressures at the hydrants were in excess of 50 lb per sq in.

"As a result of these and further experiments the following general principles appear to be established.

1. That the economical size of equipment is dependent upon the hydrant pressures available and the length of hose used.

2. That when the pressure at the nozzle is in excess of 25 lb per sq in, water is delivered thru a ¾-in nozzle faster than it can be properly used by 2 men, and that it is accompanied by excessive splashing.

3. That when the pressure at the nozzle is less than 18 lb per sq in, water is not delivered fast enough to keep up with the men nor with force enough to enable them to do effective work.

4. That the smallest size hose which will give pressures at the nozzle between 18 and 25 lb is the most economical for use.

5. That the better results can be secured by spraying ahead as far as the stream will reach, to give the material on the street a preliminary soaking prior to the direct flushing, than can be secured by the direct flushing of a dry pavement.

6. That larger quantities of water are required to clean rough pavement than smooth, and therefore a slightly larger nozzle may be used to advantage. It is estimated that a ¾-in will be satisfactory for asphalt and a 1-in for rough Belgian block.

7. That shut-off nozzles are necessary whenever working in traffic, both to save water and to prevent accidents.

8. That where water mains are large enough for proper domestic and fire supply, flushing will not interfere with the ordinary household use.

9. That a hose reel will enable the gangs to do more work with the same expenditure of energy and at the same time lengthen the life of the hose.

10. That by the adoption of procedure which prevents any back tracking of the equipment, over 4 miles of walking can be saved per gang per 8-hr day in covering a given amount of street, as compared with the procedure commonly used in the past, which saving enables the gangs to do more work.

"As a result of the studies and conclusions reached, a new hose reel, new hydrant equipment and improved procedure were adopted by the department and put into effect. The procedure may be outlined as starting with the hose reeled with the nozzle on top, commencing to unreel when at a distance equal to the length of the hose from the hydrant, unreeling toward the hydrant, placing the reel on the sidewalk near the hydrant, flushing from the point nearest the nozzle past the hydrant and as far as the hose will reach beyond the hydrant toward the nozzle, thus completing the area served by a single hydrant. Whenever moving hose, the hydrant man is required to pick it up in loops and drag it ahead in such a way that it will not cross other loops, and he is expected to keep a loop at the nozzle end, even with or slightly ahead of the nozzle man so that the latter will be free to move without assistance at all times.

"While previous to the adoption of the new methods and procedure it was seldom possible to flush effectively much over 25 000 sq yd of pavement per day, it is common now for a 2-man gang to cover from 30 000 to 45 000 sq yd in an 8-hr day, making as many as 45 or 50 connections to the hydrants. This means unit costs for labor and equipment of 11.9 to 17.8 cents per 1000 sq yd. The first cost of the equipment is approximately as follows:

Three 50-ft lengths 2-in rubber hose* at 54 cents	$81.00
One ¾-in shut-off nozzle	7.00
One 2½-in to 2-in reducer, hand swivel type	2.25
One hydrant key	0.11
One hose reel	30.00
	$120.36

*Rubber covered hose is preferable to cotton jacket hose for his work."

Note: The above costs appear to be exclusive of water and removal of dirt, and of course a 2-man gang can not clean as thoroly a dirty business street as a larger

gang brooming the entire area of the pavement behind the stream of water. The costs given for the gang method are 45 cents per 1000 sq yd, Philadelphia and Washington.

Comparison of Machine and Hose Flushing. Of the methods of street cleaning in general use the hose is unquestionably the most efficient. In machine cleaning the rate of speed thru the entire width and length of the street is the same. It is obvious that some sections of the pavement require more effort to entirely remove the dirt which has a tendency to stick to the pavement than they ordinarily receive in the regular process of machine cleaning. In the hose method of flushing pavements where such a condition represents itself the hose is pointed on this area of the pavement until the dirt is entirely removed, and likewise a less amount of water and effort is used to clean the sections of pavement that are comparatively clean. In the machine method of flushing the same quantity of water and the same pressure is exerted on the entire area of pavement, irrespective of the amount of cleaning required. It is a fact, however, that the hose flushing of business streets carrying a considerable amount of traffic which constantly get rather dirty, is more expensive than the automobile flushing, but likewise it is more effective.

Blockmen Cleaning. Pick-up and spot cleaning by hand patrol blockmen is an auxiliary method of cleaning, and is intended only to supplement the regularly scheduled machine cleanings. This method of cleaning is confined principally to highways where the character and volume of the traffic and the nature of the surroundings make its use desirable or necessary in the interval between the regular machine cleanings. To each patrol blockman should regularly be assigned a definite area of highway pavement to be kept clean. This area may vary between 2 500 and 15 000 sq yd, depending entirely upon the specific conditions of requirements of each assignment. The equipment furnished to each blockman should consist of a portable bag or can carrier, one or more burlap or canvas bags or metal cans, a pan scraper, a push broom, a hand broom, a sprinkler can, and a fire hydrant key and reducer. The work performed by the blockmen should include picking up paper and other refuse which finds its way on to either the footway or the roadway and sweeping up and removing animal droppings and detritus as soon as possible after it accumulates in order to prevent its being scattered by wind or traffic. The material to be removed is either scooped up in the pan scraper or swept into a pile and then removed. Each blockman should be provided with a sprinkling can and should sprinkle the pavement before sweeping in all instances where the dust will annoy passing pedestrians. The blockmen should be required to place in the bag or can, which is mounted on the carrier, all dirt and other refuse or waste paper collected. These filled bags or cans should be promptly removed by collection vehicles which should call at regular intervals each day. Cleaning by patrol blockmen will produce very effective results if the work is performed under the supervision of competent foremen, otherwise there is a general tendency on the part of the men to shirk.

Experimental Vacuum Cleaners. The methods of cleaning that have been described in detail are only those in general use. For a number of years experiments have been carried on with vacuum cleaners, and as a matter of fact several types of vacuum cleaners are in use in some of the cities of the United States. The principal disadvantage of the regular vacuum cleaner is its inability to clean the streets in wet weather. This would make it impossible to use this type of machine in eastern cities during wet days in the summer and most of the winter months. A type of machine will in all probability eventually be in general use that will consist of a combination vacuum

cleaner and sweeper, so that it could remain in constant use on days when it rains after the cleaning equipment is at work. In Los Angeles and St. Louis there have been very extensive experiments carried on with the vacuum cleaner.

Alley Cleaning. From a sanitary standpoint, the cleaning of alleys is of particular importance, especially in the more thickly populated portions of a city and during the summer season. An alley cleaning gang unit should consist of 1 foreman, from 6 to 10 laborers, equipped with at least 150 ft $2\frac{1}{2}$-in hose with a nozzle, a portable hose reel and push brooms, and one or more water-tight metal dirt collection vehicles. Depending upon conditions, some alleys are flushed while others are cleaned by sweeping. In flushing an alley, the stream of water should be played as far up the alley as possible, and one or two gangmen beginning at the high point or end of the alley should sweep down grade toward its outlet. The dirt and rubbish swept out of the alley should be piled in the gutters of the roadway opposite the alley, removed at once and the site cleaned. If necessary, the alley should be flushed and swept a second time after the bulk of the dirt has been removed. If an alley is only swept, the work is performed in substantially the same manner as previously described. An alley cleaning gang should sweep and flush approximately from 30 000 to 50 000 sq yd of alley pavement in a day of 10 working hr.

Road Cleaning. Included in this category must be considered all highways with roadways of such materials as earth and water-bound broken stone and gravel. Due to the varying road conditions encountered practically all of the work must necessarily be performed in such a manner as may be required by the conditions existing on the specific road rather than in accordance with definitely prescribed methods of operation. However, in the more closely built-up portions of the suburban sections, the road cleaning work more nearly approaches in methods of operation, the work performed by gangmen on the city streets. The road cleaning work gang unit should consist of 1 foreman, 6 laborers, who are equipped with push brooms, shovels, picks, hoes, rakes and sewer inlet hooks and rakes, and one or more dirt collection vehicles. Due to the variety of the work performed by the road cleaning gangs it is not possible to indicate in concrete figures the amount of work that such a gang can do in a day.

Sewer Inlet or Catch Basin Cleaning. In order to insure the prompt disposal of all surface drainage and storm water, it is necessary that the traps of all sewer inlets be kept clear of obstructions or accumulations of muck. To provide for this, it is necessary that sewer inlets be periodically inspected and cleaned. On paved streets or roads, the sewer inlets should be cleaned at least once every 2 weeks, but if the inlet is adjacent to an unpaved street or is otherwise so located that dirt is liable to be washed into it, more frequent cleaning will be necessary. The sewer inlet cleaning gang unit should consist of one or two laborers and a dirt collection vehicle. The dirt can be loosened and lifted out of the sewer inlet by means of an inlet hook and an inlet rake, the latter of which consists of three flat parallel prongs about 10 in in length attached at right angles to a long handle. The removed dirt is piled in front of the inlet and promptly removed in water-tight and covered metal-bodied vehicles. If the pipe connection between the inlet and the sewer is obstructed, the water is baled out of the inlet trap and the inlet man after entering the inlet endeavors to remove the obstruction by hand. If not successful, a hose line from a fire hydrant is then inserted into the inlet connection and the dirt is forced thru the

connection into the sewer. If the obstruction is such that it will not yield to water pressure, it is necessary to make an excavation in the street or road and remove the choked section of pipe.

Cleaning Methods Dependent upon Type of Structure. The methods of construction of inlets and catch basins adopted in the different parts of the country have a certain bearing on the efficiency of cleaning. A type of inlet commonly used in a large eastern city is built partly under the sidewalk and partly under the roadway. It has the advantage of securing a much larger basin area and also does away with cast iron grates or cover plates in the roadway gutter, which are objectionable owing to the frequency with which they must be replaced on heavy traffic thorofares. In this type of inlet, a circular cover similar to an ordinary manhole cover is inserted in a large granite block set in the sidewalk directly over the basin. The catch basin is, therefore, cleaned from the sidewalk instead of the gutter, the principal objection being the uncertainty of thoroly cleaning that section of the basin lying outside of the trap-stone or under the roadway. It is also, to a limited extent, objectionable from a sanitary standpoint as, in the operation of cleaning, the removed muck very often gives the sidewalk a dirty appearance unless extreme care is taken. While the type of inlet referred to is heavier in construction, has greater capacity and is more economical in maintenance, the street inlet or catch basin is more universally used because of its greater adaptability to the needs of cleaning. Automatic or self-cleaning inlets do not have the trap feature. They are built with a large basin from which the dirt is directly transferred to the sewer thru a pipe connection, attached to the sewer at a steep angle. Such inlets are only practicable where the sewers are laid on a heavy grade, insuring the removal of all refuse and other materials due to increased volume and velocity of flow.

Mechanical Cleaning. A mechanical device, known as the hydraulic inlet cleaning machine, operates on the hydraulic pump principle. A metal body mounted on an automobile truck receives the muck direct thru a hose inserted in the inlet catch basin. A continual flow of water from the street plug to the inlet is maintained, while the cleaning operation is in progress. The contents of the inlet, dirt and water combined, are drawn upwards thru the hose, the pumping power being supplied by the automobile engine and extra gearing attached to the truck for the purpose. After depositing the contents of the inlet in the truck body, the heavier materials sink to the bottom and the excess water is released thru valves and is returned to the inlet. This process continues until no dirt remains in the bottom of the inlet.

Use of Muck Pan. In some localities, the hand cleaning method has been superseded by the introduction of a muck pan, or tight sheet-iron receptacle, so located in the inlet as to catch the heavier street sweepings, the surface water coming down with the dirt seeping thru vent holes into the inlet basin. The operation of cleaning the inlet consists of removing the receptacles by means of hooks and dumping the muck direct into the metal body vehicles. This method requires constant supervision in order to prevent overloading of the receptacles and proper maintenance both of the receptacle and the inlet. Its principal advantage is in keeping heavy solid particles from reaching the inlet neck and choking it.

Winter Cleaning. Winter street cleaning in the latitudes of the northern states is probably the most trying problem with which a street cleaning

department has to deal. Dirt continues to accumulate on the streets regardless of the weather and temperature conditions. In the North, the roadways are covered with snow and ice intermittently thruout the winter season, while in the South, snow storms and freezing temperatures are rare. Under the former conditions, the street cleaning problem is largely one of pick-up or spot cleaning by gangmen while the streets are covered with snow and ice, and of machine cleaning whenever the equipment or forces can be used to advantage. Under the latter conditions, however, the street cleaning work progresses quite similarly in both the winter and summer seasons. In certain of the northern states, there is a continuous alternation of freezing and thawing temperatures thruout the winter. In situations of this character, immediate advantage should be taken of every opportunity to do machine or gang cleaning or flushing. To be fully prepared in this matter, it is necessary to keep in close touch with the Weather Bureau and take advantage of anticipated mild weather during which the machine or other cleaning equipment and forces can be operated. It is also of considerable advantage to assign an inspector to each equipment stable to direct the mobilization and dispatch of such of the equipment and forces that it may be possible to use. The instructions issued by these inspectors can be governed more or less by definite prearranged plans considered in conjunction with certain kinds of weather forecasts and observed temperature conditions at certain hours of the day, especially during the morning hours. The governing idea is to have the equipment and forces prepared and if possible on their respective routes ready to begin cleaning operations as soon as the weather and temperature conditions permit this being done. When freezing temperatures prevent the use of water, all machine cleaning must necessarily be suspended in favor of hand cleaning by gangmen. This necessitates increasing the regular cleaning forces at least 40%. In Philadelphia, it has been found that between the middle of Dec. and the middle of March, the machine cleaning equipment can be operated advantageously only on approximately 50% of the working days. All hand cleaning gangs should be under competent and constant supervision, and the gangmen should be equipped with push brooms, hoes, picks, and shovels to facilitate the removal of both loose and frozen dirt and also dirt covered snow and ice. In all winter cleaning, great care should be taken to keep the dust nuisance down to an absolute minimum, as this is often a greater inconvenience and menace to the public than an unclean street. The solution of the winter cleaning problem is principally in taking prompt advantage of every opportunity to work and not in assuming that because of the adverse conditions the streets cannot be well cleaned, little or no effort should be made to clean them. If full advantage is taken of every opportunity a very considerable amount of cleaning can be done and aside from this the municipality will not have to face the problem of removing an excessive accumulation of dirt from its highways with the advent of spring weather.

Relative Ease of Cleaning Different Pavement Surfaces. The effectiveness with which a method of street cleaning can be applied is governed to a considerable extent by the character of the roadway surface cleaned and its physical condition. In making a comparison between the several types of pavement it will be assumed that the roads and pavements considered are new, or in other words, in perfect condition. Assuming further that the ideal road or pavement will have an arbitrary value of 10 with respect to the ease with which it may be cleaned by the method best adapted, the

several types of highway pavements in general use will have the following relative values:

Type of Road or Pavement	Relative Value
Sheet-asphalt	10
Bituminous concrete	9
Wood block	9
Bituminous macadam	8
Vitrified block	8
Cement-concrete	7
Stone block	6
Water-bound macadam with bituminous surface treatment	4
Water-bound macadam	2
Gravel	1
Earth	1

4. Street Cleaning Equipment

Description of Equipment. The minimum quantity and character of equipment necessary for the prosecution of the street cleaning work should be definitely indicated in the specifications and should be of approved construction to fully meet the following requirements:

Squeegees. The horse-drawn squeegee cleaning machines should have a water tank with a capacity of about 500 gal and a cleaning roller set obliquely and geared or chain-belted to the rear axle and having a steel axis and rubber spiral fins.

Automobile Flushers. The automobile flushing machines should be motor-driven high pressure flushing machines of standard design, mounted on a chassis having a capacity of not less than 5 tons, and having a tank for water with a capacity of at least 1200 gal and some form of motor-driven pumps by which the water may be discharged from the nozzles with a pressure of from 35 to 60 lb per sq in, as may be directed, and a capacity to deliver from 100 to 150 gal per min from each nozzle. The machine should be so equipped that the pressure designated can be maintained thruout the entire period of discharge of the water. The nozzles must be elongated, of approved form, and so constructed that their direction may be changed and adjusted as required, and permanently set at any given angle. The machine should be capable of operating at a rate of speed of not less than 3 nor more than 8 miles per hr.

Machine Brooms. The horse-drawn machine brooms should be a 4-wheeled vehicle and have a roller set obliquely and geared or chain-belted to the rear axle. The roller should have a wooden axis and split bamboo bristles, whose length when new shall not be more than 14 in from the axis. Machine brooms should be provided with adequate dust and mud guards.

Sprinklers. The sprinkling machines should be drawn by 2 horses and be of an approved standard type of modern construction substantially built to withstand exceptionally heavy service. The valves should be adjustable to varying swaths.

Collection Vehicles used for the transportation of dirt should have water-tight metal bodies to prevent the contents from leaking when wet. They also should have metal covers to prevent dry contents from being blown out. The bodies of these vehicles should be low, to facilitate their loading and to eliminate the necessity for tossing dirt up any considerable height into the vehicles, which invariably results in more or less of it being scattered by the wind.

Inspection and Adjustment of Equipment. MACHINE BROOMS. In order to get proper results, from both the standpoints of cleanliness and of economy, the machine brooms should be inspected at frequent intervals and so adjusted and operated as to produce their maximum amount of satisfactory work. In the matter of adjustment, special attention given to the following details will do much toward producing satisfactory cleaning results: The broom roller should at all times be so adjusted that its

axis is parallel to the surface of the pavement, otherwise the broom will wear into the shape of a truncated cone, which results in poor work, and necessitates the discarding of the broom much sooner than if it had worn evenly. The broom roller should also be so set that it will press firmly down upon the surface of the pavement, and not merely drag along, otherwise the bristles will not properly engage and dislodge the dirt.

SQUEEGEE MACHINES should be inspected at frequent intervals to see that they are properly adjusted. When not actually engaged in cleaning, the water outlets on the squeegee machine should be shut off and the rubber broom raised a few inches above the pavement surface to prevent the resistance of the rubber fins being impaired or the fins damaged or unnecessarily worn. The following considerations are essential to obtain good results in squeegee cleaning work: The rubber fins should not be torn, distorted or worn thin and should show a proper amount of live resistance. When the average length of the fins projected from the spindle is 3 in or less, or when the width of swath is reduced 1 ft, the fins should be renewed. All water discharge valves should be kept in good condition as leaky valves cause considerable loss of time both in loading water and in working due to the fact that some of the water is constantly wasted and not producing effective results. The axis of the rubber broom should be approximately parallel to the surface of the pavement to prevent the fins wearing unevenly and not properly cleaning the pavement. The fins should press upon the surface of the pavement evenly and firmly and not simply skim over it. The essential function of the fins is not simply to push the water over the pavement but actually to scrub it.

Identification of Equipment. For the purposes of identification, each vehicle should bear on each side a blue enameled steel sign, lettered in white, containing the inscription, Bureau of Highways—D.P.W., followed by the designating number of the district and the serial number of the vehicle. A small blue enameled steel sign, indicating the district number and the serial number of the equipment should be also attached to all bag carriers forming a part of the equipment of the blockman. No duplication of serial numbers should be permitted in any one district. No other signs or lettering should be permitted on either the vehicles or harness. The contractor should be required to keep in stock at all times a sufficient supply of rubber fins, machine brooms, and extra parts to maintain in constant service the minimum force of equipment required by the specifications. The contractor must also see that the cleaning machines are at all times so adjusted that the bristles of the machine brooms and the fins of the squeegees will thoroly accomplish the cleaning results intended. All gangmen engaged in machine, alley, inlet and road cleaning should be provided by the contractor with hand brooms, shovels, picks, hoes, rakes, inlet muck rakes and hooks, and such other equipment as may from time to time be found necessary to properly perform their duties.

Philadelphia Practice Pertaining to Painting of Equipment. It was required that all vehicle equipment be painted at least three times during the year with standard paints, specifications for which are prepared by the Bureau of Highways, and issued to the contractor. If three paintings do not preserve the permanency of the distinguishing colors, painting was required to be done more frequently. The colors of the painting required for the several types of vehicle equipment were as follows: Machine broom, green for body, red for running gear; squeegees, flushers, and sprinklers, yellow for body, red for running gear; bag carriers, maroon; inlet dirt carts and street dirt wagons, brown. The equipment was required at all times to be maintained in a cleanly condition and the contractor was required to install adequate cleaning facilities within his stable or yard as the cleaning of equipment in the street was not permitted. The contractor was also required to present all vehicles and other equipment for inspection at such times and places as might be designated by the district engineers.

5. Street Cleaning Cost Data

Unit Costs of Street Cleaning. Unit cost data covering the several methods of street cleaning used in Philadelphia and Washington are given in the following analyses:

Method of Cleaning	Unit Cost per 1000 Sq Yd of Pavement Cleaned	
	Philadelphia 1916	Washington 1915–1916
Machine broom, horse-drawn equipment	$0.268	$0.186
Squeegee, horse-drawn equipment	0.156	0.139
Machine flushing motor-driven equipment, Philadelphia; horse-drawn equipment, Washington	0.157	0.293
Gang hose flushing	0.474	0.422
Patrol by blockmen	0.152	0.157

The above costs include the removal of street dirt and direct supervision only.

The Philadelphia Unit Costs are based upon the following daily rates of compensation or cost for the several classifications of labor and equipment as indicated.

Classification	Rate per Day
Labor:	
Superintendent	$4.00
Foreman	2.50
Gangman	1.75
Blockman	1.50
Dumpman	1.50
Equipment Units:	
Machine broom, horse-drawn	5.50
Squeegee, horse-drawn	6.00
Flusher, motor-driven	15.00
Sprinkler, horse-drawn	5.00
Dirt cart	3.50
Dirt wagon	5.00

High-Pressure Machine Flushing. Considerable and increasing interest has been evidenced in connection with the high-pressure machine flushing method of street cleaning. The following cost data based upon a working season of 300 days; one 8-hr shift each, is given by Parlin (32) in Table I:

Table I

City	Type of Flushing Equipment	Data per 1000 Sq Yd of Pavement Cleaned	
		Cost	Gallons of Water Used
Chicago	Motor-driven	$0.150	400
Los Angeles	Motor-driven	0.126	450
Rochester	Motor-driven	0.189	440
Worcester	Trolley car	0.186	450
Detroit	Horse-drawn	0.454	700
Milwaukee	Horse-drawn	0.256	400

Cost of Street Cleaning with Motor Equipment. There is no question but that the entire street cleaning equipment in use will eventually be motor equipment. The automobile flusher is very efficient and satisfactory; automobile squeegees and machine brooms are in use in foreign cities and to some extent in this country. In Toronto and Philadelphia during 1916 considerable of the street dirt has been collected and hauled to the dumps by motor equipment and has proved a considerable economy over the horse-drawn equipment. The following is a test of a motor street scrubber:

Table II.—Cost per Day of 10 Hr

First cost of machine		$6100
Depreciation, life of machine, 1200 days	$5.08	
12 gal gasoline at 23 cents	2.76	
2 quarts oil at 15 cents	0.30	
Tires, 25 miles, at 2½ cents	0.63	
Renew machine broom $10, every 6 days	1.67	
Renew squeegee $30, every 100 days	0.30	
Chauffeur	3.00	
Helper	2.00	
18 000 gal water at 4 cents per M	0.72	
	$16.46 per day.	

Records of Tests. Nov. 27, 1916: Time actually worked, 6½ hr; yardage covered, 74 181 sq yd; reduced to 10-hr day, 114 000 sq yd; cost per 1000 sq yd, $0.144. Nov. 28, 1916: Time actually worked, 7⅝ hr; yardage covered, 83 603 sq yd; reduced to 10-hr day, 109 000 sq yd; cost per 1000 sq yd, $0.151. Remarks: Average efficient operating speed, 3½ miles per hr; capacity of tank, 900 gal; effective swath, 7½ ft; gallons per 1000 sq yd, 165; average time to empty tank, 26 min: average time to fill tank, 7 min; average mileage for 10-hr day, 25.

Unit Costs of Cleaning Different Types of Pavements. The cost of cleaning of course varies with the character of pavement. The following costs were compiled from special tests, cleaning the various types of pavements by the machine broom method in Philadelphia in 1914. These costs are exclusive of the cost of water:

Table III.—Machine Broom Work per 1000 Sq Yd

Granite Block			Brick		Wood Block	Sheet-Asphalt	
Traffic			Traffic		Traffic	Traffic	
Heavy	Medium	Light	Medium	Light	Medium	Medium	Light
$0.292	$0.233	$0.210	$0.236	$0.201	$0.232	$0.208	$0.174

The annual cost per square yard of cleaning in the different cities is of very little value unless analyzed; for instance, the above costs of cleaning per yard per year in the different Boroughs of New York City in 1914 compared with the cost of cleaning per yard per year in Philadelphia show that the cost simply varies with the density of traffic and population and the consequent amount of cleaning required. The cost, in the Borough of Manhattan is necessarily very much greater than the cost in the Borough of Brooklyn and the Bronx. It will be observed that the cost of cleaning in Philadelphia has considerably increased in the last five years. This is entirely due to the fact that there never was enough cleaning provided for in Philadelphia. The cost of cleaning in Philadelphia in 1917 is very nearly the same as the cost of cleaning in the Borough of Bronx and Brooklyn, New York City, for 1914, whereas, in order to obtain the same degree of cleanliness, the cost should be somewhat higher in Philadelphia than in the Boroughs of Brooklyn and the Bronx.

Table IV.—Average Annual Costs per Yard of Street Cleaning in New York and Philadelphia

	Cost per Sq Yd of Pavement	Cost per Mile of Highway
New York City, 1914		
Borough of Manhattan	$0.305	$6400
Borough of Brooklyn	0.092	1582
Borough of Bronx	0.096	886
Greater New York	0.168	3136
Philadelphia		
1913	0.058	926
1914	0.065	1062
1915	0.064	1024
1916	0.069	1104
1917	0.101	1629

Average Annual Costs of Street Cleaning. There is no standard for the cost of cleaning per yard per year. The cost is usually governed by the degree of cleanliness required in the different cities and the amount of money available for the performance of the work. In time there will unquestionably be a more or less standard degree of cleanliness required in all of our cities, and until such time arrives the cost per yard per year in each city is of no value with respect to the efficiency with which the work is performed or the degree of cleanliness obtained. It simply indicates the amount of money expended in the respective cities per yard per year for this purpose.

Per Capita Unit Costs of Street Cleaning. Unlike most other classes of work in connection with which it is possible to utilize unit cost data in interpreting results accomplished, street cleaning does not afford the same possibilities. This is due largely to a number of indeterminate factors principal among which is the lack of definition of the relative degree of cleanliness demanded, the condition of the pavement, the use of equipment best adapted to the pavement cleaned, and whether the service is performed under the contract system or by municipal forces. However, in Table V unit costs for street cleaning per capita per annum are given, having been compiled from official reports from the cities indicated:

Table V

City	Year	Estimated Population	Cost per Capita per Annum
Philadelphia	1916	1 725 000	$0.714
Washington	1916	357 749	0.831
Boston	1915	755 905	0.729
Cleveland	1914	650 000	0.455
Detroit	1912	678 000	0.580
Cincinnati	1914	400 311	0.504

Utilization of Street Sweepings. In recent years a number of claims have been made relative to the possibility of utilizing street sweepings as a fertilizing material and of the possibility of deriving revenue therefrom. This subject was quite fully discussed in a report submitted relative to

New York City conditions. The facts noted indicate substantially the status of this matter in 1917. This report states that:

"It is often asserted and as frequently denied that street sweepings have a considerable value as fertilizer for agricultural land. Theoretically, street dirt is of much value as a fertilizer, and possibly of some use as a fuel, but the practical difficulties of utilizing its useful ingredients are too great to make it of substantial benefit. It is in fact a mixed refuse and its composition varies in different seasons in different cities and in different parts of the same city. The elements contained in the sweepings that are of fertilizing value are nitrogen, phosphoric acid and potash. The quantities of these elements found in street sweepings vary within quite wide limits, and are derived almost wholly from the animal excrement. It is difficult to place any fair market value on the nitrogen, phosphoric acid and potash contained in street sweepings, because the market price of these elements not only varies at different times, but the form in which each is found modifies its value for fertilizing purposes. Probably only about one-half of the phosphoric acid is in a soluble form immediately available as plant food. A rough estimate of the values of these elements in 1 ton of street sweepings is at the present, as follows:

8.52 lb nitrogen, at 15 cents	$1278
8.40 lb phosphoric acid, at 5 cents	420
7.32 lb potash, at 5 cents	366
Total	$2064

From this gross value must be deducted the cost of transporting the sweepings to the lands where they are to be used, and their value compared with other fertilizers also must be considered. The great bulk of the gross material that must be handled is the difficulty in attempting to utilize these sweepings on farm lands, since nearly 98% of the mass is inert material. Furthermore, the cost of distributing the street sweepings on farms is disproportionate to their value; and, under usual conditions, sweepings are a far less economical and convenient material for the farmer than the commercial fertilizers to be had in the market. As the better grade of street sweepings have only about half the fertilizing value of stable manure, ton for ton, and as it is becoming more and more difficult to dispose of even the latter material to farmers at a price that will cover the cost of delivery, it will be appreciated how hopeless it is to expect any successful disposition of street sweepings in this way. The use of street sweepings alone for filling lands has been condemned by many sanitary authorities, because the organic matter may undergo fermentation, with exhalation of ammonia or other gases deleterious or obnoxious to those living in the vicinity. Where street sweepings, rich in organic matter, are deposited alone in large masses, there may be ground for serious annoyance and possible injury to health."

6. Administration and Organization of Street Cleaning

Municipal Force vs Contract System. Street cleaning work which from its very nature involves so many more or less irregular operations necessitated by the constantly varying traffic, climatic, atmospheric and local conditions for which it is not always possible to fully and definitely prescribe, requires constant supervision thru personal field inspection of the work performed by each gang or other unit of the organization. This work, as it is also the case with street repairs and other work of a character where it is not possible to fully and definitely specify the detailed manner in which the work shall be performed, should be carried on by municipal forces instead of by the contract system. This necessity is emphasized by the consideration of the dual overhead charges, disproportionate to the cost of the work, which result from the city and the contractor both being required to maintain separate supervisory inspection forces, each of which, however, perform duplicate service, and both of which must ultimately be paid for out of municipal funds. Irrespective, however, of the system under which street cleaning work is performed, there are certain well-defined fundamental, administrative and engineering considerations which

are generally recognized as governing factors in the successful and economical performance of the work.

Purposes Sought Thru Organization. In planning the organization of street cleaning work by contract, the following purposes should be sought:

1. The consideration of street cleaning as an engineering function and the placing of the routine supervision work under the control of district engineers, who are also charged with the responsibility of the construction and maintenance of the pavements in their respective districts, street cleaning being an important part of the maintenance of pavements and should be controlled by the same organization.
2. The classification of streets and roads with respect to the necessary frequency of their cleaning.
3. The institution of specifications that indicate in a definite and concise manner the quantity and character of work to be performed; the minimum force and character of labor and equipment required in the work and the most approved methods of its performance.
4. The institution of a schedule of deductions from the contractor's compensation which would adequately provide for all derelictions relative to labor and equipment required but not furnished, work neglected or improperly performed and other violations of the specifications that tended to lower the standard of the work as a whole.
5. The inauguration of schedules defining definite routes to be followed and the character of equipment to be employed in the performance of the work.
6. The establishment of a system of inspection designed to give the bureau as complete control as is possible with an adequate force of inspectors over the number, condition and character of forces and equipment employed by the contractor, his methods of operation and the results obtained.
7. The adoption of a modern system insuring the prompt and careful investigation of all reports received from the general public of observed instances where the street cleaning work was neglected or not properly performed; and the encouragement of coöperation on the part of the public in reporting all matters of this nature coming to their attention.
8. The installation of unit cost records by which it is possible to determine the actual cost to the contractor of the field work performed, which materially assists in the administrative control of the work, and serves as a basis upon which may be determined the fairness of the prices bid by the contractors, and also makes possible the comparison of costs for similar work in different localities and under varying conditions.
9. The installation of report forms that insure a detailed and accurate record of performances, forces employed, and other pertinent data.
10. The establishment and maintenance of standards of appearance, including the uniforming of all foremen and workmen, and the periodical painting in distinctive colors each type of equipment used on street cleaning work.
11. The encouragement of friendly rivalry among the several contractors, and the promotion of *esprit de corps* among the workmen by the institution of an annual public inspection and parade with the awarding of prizes to the contractors attaining the highest ratings for appearance of men and equipment.

The Administration and Organization of Street Cleaning in Philadelphia as developed by the author while Chief of the Bureau of Highways and Street Cleaning, 1912 to 1917, will illustrate the details of methods required to properly control this work.

Routine Supervision. The regular supervision of the street cleaning work was under the jurisdiction of the several district engineers who also had charge of the collection of ashes, rubbish and garbage and the construction and maintenance of pavements in their respective districts. In addition to maintenance a close supervision over the field inspection work performed by the several street cleaning inspectors assigned to each district, and making adjustments to the work schedules of the order or manner in which the street cleaning work should be performed, the district engineer also kept in touch with the complaints received from the general public concerning the performance of the work.

Investigation of Complaints. In all branches of the public service coöperation on the part of the citizens in reporting apparently unsatisfactory conditions coming to

their attention is generally recognized as a most valuable asset toward the attainment of ideal conditions. On this account it should be the policy not only to invite constructive criticism but also to furnish every facility for so doing. Upon the receipt of a report at the main office of the improper or non-performance of street cleaning work there should be originated a complaint form upon which is indicated the location and nature of the reported conditions, the date, the name and address of the complainant, the serial number of the complaint and the district number. A record of the existence of the complaint should be made in a complaint register by recording the complaint serial number, the name or address of the complainant, the district number and the date of the complaints transmitted to the district office for investigation. Upon receipt at the district highway office, the complaint should be promptly issued to an inspector for investigation and report. In instances where a complaint is originally received by the district office it should be investigated as usual and in the meanwhile the main office should be advised by telephone of its existence and a serial number assigned to it. After being approved by the district engineer the complaint forms should be forwarded to the main office. Upon receipt of the complaint form at the main office the open entry in the complaint register should be closed out by entering the date of the complaint's return. To insure that no complaint investigation is neglected for an unreasonable length of time or overlooked the complaint register should be checked each week and all complaints for which final reports have not been received investigated.

Record Forms. To assist in the administration of the street cleaning work the following record forms were provided: (1) Work routine schedules; (2) inspectors' daily reports; (3) district engineers' daily reports; (4) special test unit cost data reports; (5) special test unit cost data summary forms; (6) monthly unit cost data reports; (7) complaint forms; (8) complaint register sheets.

Work Route Schedules. To insure that the street cleaning work may proceed in orderly sequence and with a minimum of lost motion and the least inconvenience to the public, work or route schedules should be compiled outlining the work of each gang for each working day of the week. These schedules indicate the identifying serial number of the district, route, and gang to which they apply, the character of cleaning to be performed, the quantity and character of labor and equipment to be employed, and the names, limits and character of pavement of the highways to be cleaned The number and limits of the highways included in any specific route schedule and the sequence of the cleaning was based upon the consideration of arranging the highways to be cleaned as nearly contiguous as possible and providing for a fair day's work. The planning of up-to-date and economically arranged route schedules was considered to be a very important feature in connection with the efficient performance of street cleaning work and on this account the district engineers were required not only to personally direct their preparation but also to assign an assistant engineer or inspector to constantly keep in touch with the manner in which the schedules were carried out to determine their practicability and to make any revisions necessary.

Inspectors' Daily Reports. Each inspector assigned to the supervision of street cleaning work was required to submit a daily report to the district office. In this report was indicated the following data: the district number; the date; the weather conditions; the quantity and character of labor and equipment in each gang employed on each of the several classifications of cleaning and at the dumps; the condition of the uniforms and equipment; the quantity of dirt collected; record of any derelictions; and the hours during which the inspector was on duty.

District Engineers' Daily Reports. From the several inspectors' daily reports, the district engineers compiled in duplicate a daily report, Fig. 1, for each street cleaning district, indicating in composite form all of the data shown in the daily reports of the several inspectors assigned to that district. The original copy of this report was forwarded to the main office and the duplicate copy was retained in the district office.

Unit Cost Records. To assist in the administrative control of the street cleaning work and to furnish data by which may be determined the degree of efficiency of the performance of the work, there should be compiled for each district a monthly report, Fig. 2, indicating the unit costs for each character of street cleaning work performed. This report should be compiled from the force employed and dirt collected data contained in the monthly summary and the record of the yardages cleaned as indicated in the route schedules. In detail, this report indicates for each character of street cleaning the total cost, the area and unit costs both in terms of 1000 sq yd of pavement

BUREAU OF HIGHWAYS AND STREET CLEANING

Department of Public Works Philadelphia

ASSISTANT ENGINEER'S DAILY REPORT ON STREET CLEANING

DISTRICT ____________

DATE ____________ 191

WEATHER ____________

Type of Gang	Gang Number	Foreman	Assistant Foreman	Laborer	Machine Brooms	Sprinklers	Loads-Water	Squeegees	Loads-Water	Single Wagons	Loads Dirt Snow	Double Wagons	Loads Dirt Snow	Carts	Loads Dirt Snow		FORCE AND EQUIPMENT NOT IN GANGS	
MACHINE ROOM	1																Superintendents	
	2																Foremen of Blockmen	
	3																Blockmen	
	4																Blockmen Wagons	
	5																Loads Blockmen's Dirt	
	6																Hand Mach. Brooms	
	7																Inlet Cleaners	
TOTAL																	Inlet Carts	
SQUEEGEE	1																Loads Inlet Dirt	
	2																	
	3																Flushers	
TOTAL																	Loads Water	
ALLEY	1																Extra Sprinklers	
	2																Loads Water	
	3																	
	4																Dumpmen (Dirt Dumps)	
TOTAL																	Horses (Dirt Dumps)	
HOSE GANG																		
ROAD WORK	1																Total Drivers	
	2																Total Horses	
	3																	
	4																	
TOTAL																		
GRAND TOTAL																		

____
Assistant Engineer

Fig. 1

cleaned and 1000 cu yd of dirt collected. When more refined data is desired for either engineering or administrative purposes special test cost data should be collected and compiled in the main office. This special test cost data taken collectively should cover such highways, types of pavement and classes of cleaning at such seasons as are considered to be typical of the conditions prevailing throughout the city during the entire year. For each street cleaned during these special investigations the cost data report should contain the district number, date, the classification of the cleaning, the name and limits of the highways cleaned, the length, width and area in square feet of the surface cleaned, the weather conditions, the character and condition of the

Bureau of Highways and Street Cleaning Department of Public Works City of Philadelphia	STREET CLEANING UNIT COST DATA	District No. Month of 191

Character of Cleaning	Total Cost	Distribution of Cost					Pavement Cleaned		Dirt Collected	
		Superintendence	Labor	Equipment	Water		Sq. Yds.	Unit Cost	Cu. Yds.	Unit Cost
Alley										
Blockmen										
Flusher										
Hose Flushing										
Machine Broom										
Squeegee										
Road										
Sewer Inlet							(Number)	(Per inlet)		
Totals										

Contract Price		Total number of working days in month.
Deduction		Remarks:
Paid to Contractor		
Estimated Cost		
Estimated Profit		Compiled by.

Fig. 2

pavement cleaned, the volume of the traffic, classified as either light, medium or heavy, the character, quantity and time of each class of labor and equipment employed, the quantity in gallons of water used, the quantity in cubic feet of dirt removed, and the inspector's name. These reports should be submitted to the main office where the information they contain can be transferred to a cost data summary, one summary being maintained for each classification of cleaning, which should contain in composite form the total area of the highways cleaned, the costs per 1000 sq yd of pavement cleaned in time and money of each class of labor and equipment employed, and the total quantity of gallons of water used and dirt collected per 1000 sq yd of pavement cleaned.

Labor. It should be required that all employees engaged on street cleaning work be thoroly able-bodied and capable, both physically and mentally of performing their duties in a satisfactory manner, and able to speak English satisfactorily.

Uniforms of Employees. It is universally conceded that the general effect of uniforming any working force is to not only increase the efficiency of the work thru promoting *esprit de corps* among the workers, but also to visualize to observing persons that a certain sense of order prevails in the organization. These considerations are always desirable, but especially so in connection with the municipal public service. All of the supervisory and working forces should be uniformed. Each superintendent or foreman was required to wear a dark gray uniform, consisting of a coat, trousers and cap. All other employees were provided at all times with at least two suits of white

uniforms, consisting of coat and trousers. During the months of June, July, Aug. and Sept. the blockmen and gangmen were allowed to omit coats, provided a white shirt of an approved type was worn and suspenders omitted in favor of belts. During the same months foremen and drivers were also allowed to omit coats provided an approved type of shirt of the same color as the uniform, and belt were worn. Drivers wore an approved type of brown canvas hat in the summer and a brown cap during winter. All other employees were provided with a white helmet for summer wear and a white cap for winter wear. All uniforms were required to be maintained in a clean condition and all employees wearing wash uniforms were required to appear in a clean uniform on each Monday morning. As a means of identification each employee should wear at all times a badge on his hat or cap having indicated thereon, Bureau of Highways—D.P.W., and also the identifying number of the street cleaning district. Each employee should also be provided with a three-quarter length rubber coat, rubber hip boots and rubber hat to protect them while working during inclement weather.

Working Hours. The working hours should be from 7 A.M. to 12 M. and from 1 P.M. to 6 P.M., except during the months of Nov., Dec., Jan. and Feb., when due to darkness the work should be discontinued at 5 P.M. It is desirable in the business district to perform all street cleaning work at night except during the winter months.

Annual Inspection and Parade. In order to encourage friendly rivalry between the several superintendents and to promote *esprit de corps* among the employees, and especially to afford the general public an opportunity to judge whether a proper standard is being maintained, there should be an annual public inspection of the labor and equipment of each of the several districts. This annual inspection should be in the form of a parade, and when a clean-up week campaign is to be held it is very desirable to have the parade just prior to clean-up week as a means of advertising the event. On this occasion each district should be required to have both the uniforms and condition of the equipment present the most creditable appearance possible.

COLLECTION AND DISPOSAL OF ASHES, RUBBISH AND GARBAGE

7. Collection and Disposal of Waste

Sanitary and Economic Considerations. The main factors which govern the methods of collection of ashes, rubbish and garbage are sanitary and economic considerations. The sanitary considerations require that these waste materials be collected with sufficient frequency and disposed of in a manner not prejudicial to the public health. The economic considerations relate exclusively to the methods of collection and disposal, the principal methods being the separation method and the mixed method. The separation method consists in the separation of ashes, rubbish and garbage by the householder, their storage in separate receptacles and collection by the municipal collectors in separate vehicles, while the mixed method consists in the storage of these waste materials in the same receptacle and their subsequent collection in the same vehicle. Both of these methods are sanitary. But, from an economic standpoint, in most of the cities in the United States the separation method is the least expensive. In many instances, in European cities, this is not so; the reason probably being, as statistics show, that there is about four times as much rubbish and garbage placed out for collection in this country as there is in Europe. Consequently, there would be more revenue derived from the disposal or reclamation of these materials when collected separately, than there would be in Europe. Furthermore, most of the cities in the United States are growing rapidly and afford considerable opportunity for the advantageous use of ashes as a filling material either in grading the streets or in reclaiming lowlands, etc. Therefore, it may be stated, that in most cities in the United States the separation of waste materials and the disposal of garbage by the reduction method, the reclaiming of rubbish thru modern rubbish

disposal plants and the utilization of ashes for filling material is the most economical method of handling this problem. In many of the European cities, where there is very little use for ashes as a filling material and it is not possible to derive much revenue from the reclamation of rubbish and garbage on account of the relatively small quantities placed out for collection, the mixed incineration method of waste disposal is probably the most economical. There is no question, however, that the mixed incineration method is the most convenient to both the householder and the municipality, as it is very difficult to educate the people to separate waste materials, and, as a matter of fact, the only way to insure the separation of waste materials is thru the rigid and continuous enforcement of the laws by the police.

Classifications of Domestic and Trade Wastes. The several general classifications of domestic and trade wastes and the character of the materials included in each may be enumerated and defined as follows:

Ashes, which includes ashes in an amount of 400 lb per week per building from coal or other fuel, and floor sweepings such as may accumulate in connection with the ordinary conduct of dwellings.

Rubbish, which includes all discarded materials from residences and, in a reasonable amount, from places of business, such as bottles, paper, rags, bedding, furniture, clothes, shoes, leather, carpets, broken glass, crockery, cane, metals, rubber, Christmas trees and decorations, shrubs, vines, grass and leaves, in a reasonable quantity from each building each week and also the contents of highway rubbish receptacles.

Garbage, which includes all refuse of animal and vegetable matter, which has been used, or was intended to be used, as food for human consumption, and all dead animals, or parts thereof, not intended to be used as food, in a reasonable quantity from each home or other non-commercial building and not exceeding 1 bushel from each store or stand each collection day.

Trade Waste, which includes earth, sand, brick, stone, lumber, plaster, wall paper and any other material or sweepings that result from building operations, fruits or other vegetable matter from wholesale dealers; and garbage exceeding 1 bushel in quantity, or oyster or clam shells from restaurants, hotels or other places of business.

Per Capita and Total Annual Production of Waste. In considering the per capita per annum production of waste this term will be assumed to include only the household or domestic waste materials, such as ashes, rubbish and garbage. Due to the absence of a uniform system of keeping municipal records and the different methods of service operations employed it is not possible to obtain extensive or altogether reliable data from many municipalities. Several of the larger cities are maintaining records which will give this data, and it is expected that such a practice will become universal. Table VI has been complied from official reports:

Table VI

City	Year	Estimated Population	Pounds per Capita per Annum		
			Ashes	Rubbish	Garbage
New York City, Boroughs of Manhattan, Brooklyn and Bronx........	1916	4 655 668	....	...	210
Philadelphia............	1916	1 725 000	773	86	260
Washington............	1916	357 749	416	97	292
Boston.................	1915	755 905	936	...	203
Cincinnati.............	1914	400 311	689*	...	....

*This is a composite value for ashes and rubbish combined.

In order to give a comprehensive idea of the fluctuation in the quantities of waste materials collected during the several months of the year, the curves in Fig. 3 are shown which represent the quantities of ashes, rubbish, garbage and street dirt collected and

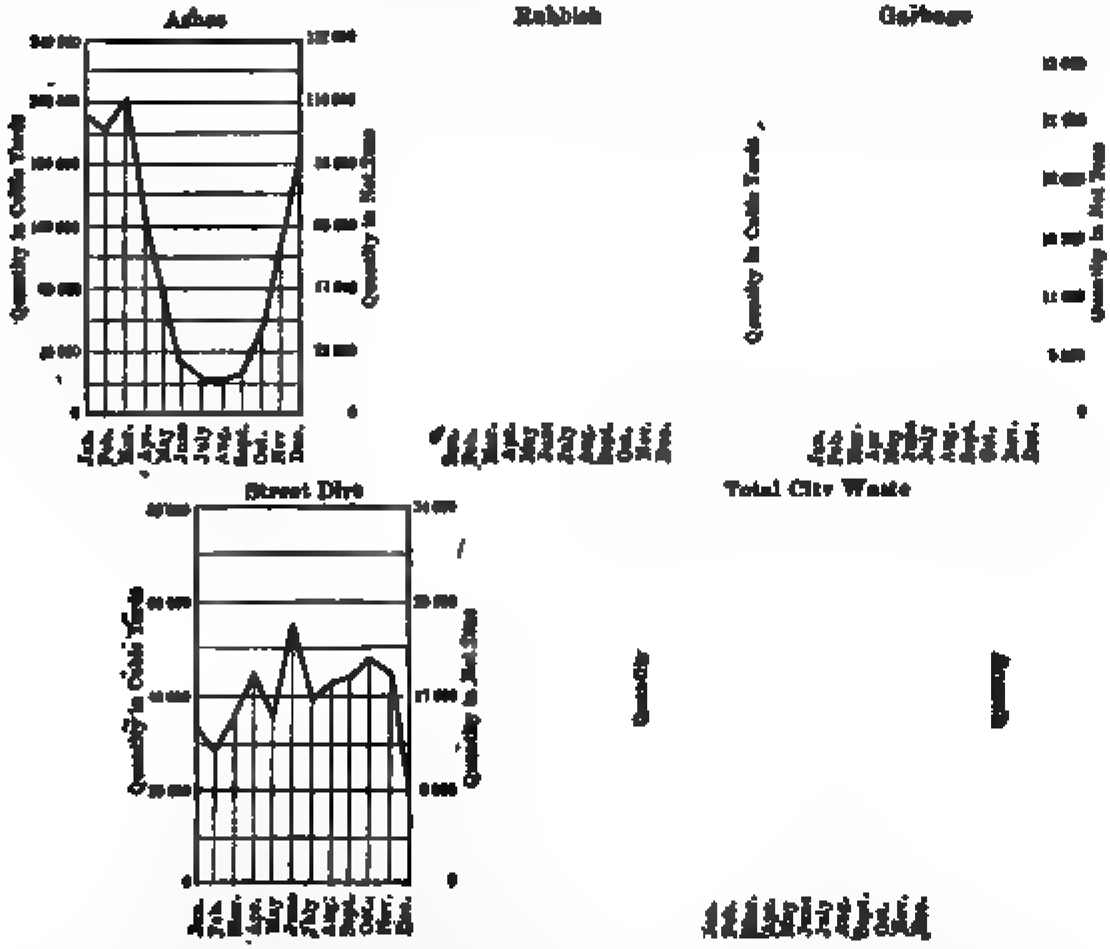

Fig. 3. Waste Collected During 1916 in Philadelphia

disposed of in Philadelphia during the year 1916. These curves may be considered as illustrative of the average conditions existing in the larger cities. It should be particularly noted that rubbish and garbage increase in quantity during the summer months while ashes increase very materially during the winter months.

Per Capita Unit Costs of Waste Collection and Disposal. The unit costs per capita for the collection and disposal of ashes, rubbish and garbage, will vary considerably

Table VII

City	Year	Estmated Population	Unit Costs per Capita per Annum			
			Ashes	Ashes and Rubbish	Rubbish	Garbage
Chicago	1912	2 287 520	...	$0.361*	..	$0.164
Philadelphia	1916	1 725 000		0.315*	...	0.216
Washington	1916	357 749	0 192	......	0.079	0.208
Boston	1915	755 905	0.303	......	0.056	0.273
San Francisco	1914	504 000	.....	...	...	0.656
Cincinnati	1914	400 811	.....	.307*	......	..
Detroit	1912	673 000		.....	.....	.162

*These are composite values for ashes and rubbish combined.

according to the method of disposal employed and whether the service is performed under the contract system or by municipal forces. The lack of a uniform and adequate system of records makes it difficult to obtain reliable data for the purpose of intercity comparison. Table VII has been compiled from official reports.

Weight per Cubic Yard of Waste Materials. Since 1910 a number of investigations have been made to determine the average weight per cubic yard of the different classes of domestic waste. Probably the most extensive investigation of this character was conducted in the District of Columbia in 1915 by Irvin S. Osborn. Based upon 41 studies of the weight and volume of rubbish, the average weight of rubbish was found to be 201.4 lb per cu yd, while the maximum weight observed was 386.8 lb per cu yd and the minimum weight 130.0 lb per cu yd. A number of studies have also been made in Philadelphia with the result that the following weights in pounds per cubic yard were determined upon: Ashes, 1100; rubbish, 220; garbage, 1100; street dirt, 850.

Collection of Trade Waste. In connection with the municipal collection of waste materials, the classification generally known as trade waste is intended to include all waste materials that result from distinctly industrial or commercial activities. While, in the interest of public health and safety from fire hazard, it is considered to be properly a municipal function to collect and dispose of all waste materials resulting from the ordinary conduct of homes and minor places of business, yet it has never been considered equitable to the tax payers at large to include as a public duty such waste materials as are produced thru the operation of business enterprises.

In Philadelphia, it is not the policy to collect or dispose of so-called trade waste at municipal expense. The few instances that may possibly be regarded as exceptions to this principle are in the case of garbage from retail stores, which is collected in a quantity not to exceed one bushel, and the concession which requires the contractor to receive and dispose of, when delivered to his disposal plant, decayed vegetables or fruits from wholesale dealers without cost to party delivering it.

Incineration Method of Mixed Waste Disposal. In general the incineration method of mixed waste disposal may be described as follows: The mixed waste, which may include ashes, rubbish and garbage, is hauled to the disposal plant and dumped from the vehicles into hoppers from which it is transported by belt conveyors to the upper floor of the disposal plant where it is discharged into large tanks or silos. The bottoms of the silos consist of a large mesh inclined grate, which moves rapidly back and forth. This device enables the material to be fed uniformly and without compression thru the conduits into the incinerating furnaces. The incinerating furnaces consist of air-tight insulated steel cylinders reinforced with thick fire brick walls and arched tops. The grate on which the material to be incinerated rests is turned continuously and carries with it in rotation practically the entire charge of rubbish. Some grates are conical and this type of grate has the advantage of giving larger grate surface for the distribution of the charge and also serves to properly direct the air currents, which insures better combustion. The revolving grate insures constant agitation of the charge thus insuring the displacement and ejection by means of gravitation of the ashes and clinkers as quickly as the combustible content of the waste has been consumed. Directly beneath the incinerating furnaces are large hoppers, which receive the ashes and clinkers ejected from the furnaces. These hoppers are equipped with controlled outlets, which permit of their contents being discharged into vehicles or cars by which it may be removed from the plant. Generally speaking, the handling of the waste from the time it enters the plant until it leaves in the form of ashes and clinkers is automatic and requires very little labor except that necessitated by periodic inspections to insure that the equipment is operating properly. However, the furnaces require constant attention. The

heat generated in the incinerating furnaces is conveyed thru flues to boilers usually of the water tube type where steam is generated, which in turn furnishes steam and electric energy, for heat, light and power purposes at the plant or elsewhere. In practically all situations where either part or all of the waste is disposed of by the incineration method, there is the same opportunity to produce more or less steam or electric power for sale. Considerable experimenting also has been carried on for the purpose of utilizing the furnace product, which is known as clinker. To a limited extent clinker has been used in making bricks and as an aggregate in cement-concrete work, but no appreciable amount of revenue has been obtained from the utilization of this material.

8. Collection and Disposal of Ashes

Collection of Ashes; practice recommended for Philadelphia by the author. Ashes should be collected from each home once each week and on a day separate from that on which rubbish is collected. The householder should be required to deposit the ashes in tight receptacles, preferably metal, upon the sidewalk near the curb. The total weight of any one receptacle and contents should not exceed 150 lb and the total quantity of ashes that will be removed from any building should not exceed 400 lb per week. When more than one building, as in the case of a row of apartment dwellings, is heated from a central heating plant, the amount of ashes that will be removed should not exceed an amount equal to 400 lb for each building so heated. If, however, the heating plant is in a building constructed and used exclusively as a heating plant, only 400 lb of ashes should be removed by the contractor. It should be required that the contents of receptacles be emptied in the collection vehicles without spilling, and the receptacles returned to the sidewalk near the curb line, carefully and without injury. Each ash collection route should be under the direct supervision of a foreman, employed by the contractor and whose duties should be confined exclusively to that route. The contractor should be required to furnish a sufficient number of laborers and vehicles to sweep up and remove from the streets all ashes blowing or spilling from the receptacles, and this force should be required to operate at a distance of not more than one block behind the collecting forces. Ashes should be conveyed to the dumps by vehicles, barges or trolley cars, the latter two being loaded by gravity from the collecting vehicles in especially constructed loading stations.

Use of Ashes as Filling Material. Clean ashes may be utilized in the grading of highways and filling in of municipally owned lowlands and also private property upon which conditions, such as mosquito-breeding pools, have been formally declared to constitute a nuisance.

Dumps for Ashes. See Art. 9.

Calorific Analysis of Ashes. As there is apparently little prospect of domestic ashes being utilized in the immediate future except as a filling material, it is rather unnecessary to investigate into its mechanical or chemical composition. Due, however, to the fact that ashes constitute a considerable portion of the domestic waste material which is disposed of in a number of cities by the mixed incineration method it is desirable that the calorific or combustible value of ashes be known. In order to determine some such data 45 samples of domestic ashes were recently analyzed by the Bur. of Mines, U. S. Dept. Int., with the average results given in Table VIII. In interpreting this data it should be noted that cinder and dust are arbitrary classifications designating respectively the larger particles and the finely-divided material which collectively constitute ashes and have been separated by sifting.

Table VIII

Material	Percentage of Weight	Moisture	Dry Material			British Thermal Units as Obtained From	
			Volatile Matter	Fixed Carbon	Ash	Sample Tested	Equivalent Weight of Dry Coal
Cinder......	51.4	2.05	3.53	51.10	45.30	7858	7932
Dust.......	48.6	4.55	5.09	15.99	78.87	2875	3074

9. Collection and Disposal of Rubbish

Collection of Rubbish; practice recommended for Philadelphia by the author. Rubbish should be collected from each home or other building once a week and on a day separate from that upon which ashes are collected. In the interest of clean streets, householders should be encouraged to store rubbish while waiting collection within their premises and should be required to display in some conspicuous place on the removal day, a notice card containing the inscription, Call for Rubbish, furnished by the contractor, indicating that rubbish is upon the premises awaiting removal. All rubbish should, however, be stored at a point on the premises readily accessible to the collector. Whether stored within the premises or on the footway, the secure bundling of rubbish or the use of bags or other suitable tight receptacles should be required in order to prevent the rubbish being scattered on the highways. The contractor should be required to furnish a sufficient number of laborers and vehicles to sweep up and remove from the streets all rubbish blowing or spilling from the receptacles and this force is required to operate at a distance of not more than one block behind the collecting forces. Rubbish should be conveyed to the dumps by either vehicles, barges or trolley cars, the latter two being loaded by gravity from the collecting vehicles, in especially constructed loading stations. After the collection vehicles are loaded with rubbish, it should be required that they be taken at once to the dump and if not reclaimed within 24 hr thereafter, disposed of, either by burning or by covering with clean earth or ashes, so as to eliminate the possibility of its becoming a nuisance by being blown over the adjacent properties.

Dumps for Ashes and Rubbish. All rubbish dumps should be provided with standard fire hydrant connection and sufficient hose to reach all portions of the dump. Both ash and rubbish dumps should be operated at all times in the manner as required by the Bureau of Health. All dumps should be frequently inspected to insure that they are being operated in a sanitary manner and with due regard to minimizing fire hazards.

Rubbish Disposal Plant. Aside from lessening the cost of the collection service thru the profits accruing from the systematic reclamation of such of the materials as have a commercial value, the establishment of rubbish disposal plants would relieve the nuisances which exist in the form of rubbish dumps thruout the outlying sections of a city, where it is frequently very difficult to maintain sanitary conditions and also to entirely eliminate the fire hazard, both of which conditions are an injustice and constitute a

menace to the health and property of the citizens living in the vicinity of these dumps. In general it may be stated that approximately 50% of all household rubbish consists of reclaimable material or, in other words, material that can be recovered and sold to produce revenue. The reclamation method of rubbish disposal such as is employed in most of the modern plants may be briefly outlined as follows: The rubbish is hauled in the collection vehicles onto an elevated platform at the disposal plant and dumped into bins alongside of which are located belt conveyors. The rubbish is raked onto the conveyor as fast as required. The conveyor then passes thru a long horizontal channel on either side of which are stationed a sufficient number of pickers to pick out what is termed the reclaimable or saleable materials. Each picker is assigned to pick out a certain kind of material; for instance, one picker's duty will be to pick out the glass bottles, another the rags, another the metals and another papers, etc. The worthless material is allowed to remain on the conveyor, which carries it to the incinerating furnaces where it is destroyed.

Mechanical Analysis of Rubbish. Comparatively few investigations have been made of the mechanical composition of domestic rubbish. This is due to the fact that such data is seldom sought except in connection with consideration of a disposal plant problem and relatively few municipal rubbish disposal plants are operated in the United States. One of the most extensive investigations of this character was conducted under the supervision of Irvin S. Osborn in the District of Columbia, during a period of 8 months, Nov., 1914, to Aug., 1915, inclusive, and the results of the mechanical analysis of 16 346 cu yd of domestic rubbish, having a weight of 32 926 lb, collected during that period was as given in Table IX.

Table IX

Material	Percent of Weight
Books	3.23
Bottles	8.44
Cardboard	9.21
Dirt	10.12
Enamelware	0.28
Excelsior	0.42
Glass	4.25
Leather	0.82
Linoleum	0.16
Matting	1.12
Mattresses	0.98
Metals	1.04
Newspapers	16.08
Paper, manila	9.69
Paper, mixed	5.32
Rags	5.82
Rubber	0.19
Screenings	11.13
Straw	0.05
Tinware	8.83
Wood	3.42
Total	100.00

Calorific Analysis of Rubbish. In connection with the consideration of the mixed incineration method of domestic waste disposal, it is essential that the calorific or combustible value be known of the predominating materials, which collectively constitute approximately one-third of the volume of all household or domestic waste. In order to make available some data of this character, the Bur. of Mines, U. S. Dept. Int., made a number of calorific analyses of rubbish as collected and it was found that 1 lb of rubbish, including dirt, metals, glass and other noncombustible materials yielded 5500 British thermal units as compared with 11 000 British thermal units yielded by 1 lb of dry coal. Analyses were also made of two samples each of the predominating combustible materials with the results given in Table X.

Selling Prices of Materials Reclaimed from Rubbish. During the period, 1914 to 1917, the prices obtained for sorted scrap and waste materials have risen steadily due largely to conditions brought about by the European War. In some instances these prices have advanced so high as to warrant their being considered abnormal and not suitable for purposes of comparison when normal conditions shall have been restored. For this reason the data here indicated has been taken from the annual report of the Division of Street Cleaning, Department of Public Service, City of Cleveland, for the year 1914, for which year the prices may be considered as practically normal. The

Table X

Material	Moisture	Dry Material				British Thermal Units as Obtained from	
		Volatile Matter	Fixed Carbon	Ash	Sulphur	Indicated Material	Equivalent Weight of Dry Coal
Books	4.40	71.20	5.10	23.70	0.35	5400	5630
	7.24	74.72	4.88	20.40	0.08		5821
Cardboard	6.00	80.30	10.40	9.30	0.15	7154	7430
	8.67	84.39	9.33	6.28	0.16		7833
Dirt	2.70	20.20	9.10	70.70	....	3661	4261
	3.70	22.27	3.87	73.86	....		3802
Excelsior	7.00	88.50	10.40	1.10	0.05	7858	8580
	9.48	92.76	6.80	0.44	0.19		8675
Leather	5.90	72.80	17.70	10.00	0.45	8240	8580
	10.33	78.64	11.18	10.18	0.45		9189
Linoleum	2.10	65.80	6.80	27.40	0.40	6266	8310
Mattresses	6.40	75.40	18.50	6.10	0.25	....	7430
Matting	10.20	82.41	8.08	9.51	0.19	....	6978
Newspaper	6.20	86.90	10.00	3.10	0.10	7485	8230
	8.67	87.41	7.84	4.75	0.11		8196
Paper, manila	5.10	88.90	8.60	2.50	0.25	7626	7840
	8.99	89.12	8.14	2.74	0.13		8379
Paper, mixed	5.30	84.80	10.70	4.50	0.15	6867	7910
	9.07	86.85	9.60	3.55	0.16		7552
Rags	3.70	89.90	8.80	1.30	0.10	7312	7410
	6.47	94.39	2.45	3.16	0.16		7818
Rubber	1.20	.....	.....	47.60	0.65	....	6620
Screenings	8.60	78.10	11.40	10.50	0.30	6483	6910
	9.97	83.11	9.08	7.81	0.46		7201
Wood	6.30	87.60	11.00	1.30	0.10	7721	8910
	8.55	87.78	10.22	2.00	0.19		8536

prices indicated in Table XI are for sorted materials recovered from domestic rubbish in the municipal rubbish disposal plant.

10. Collection and Disposal of Garbage

Collection of Garbage. It should be required that all receptacles used for the storage of garbage while awaiting collection be durable, watertight and covered and preferably made of metal, and that the receptacles be stored in a safe place in the yard where they are not likely to be overturned by passing traffic and will be readily accessible to the collector. The collectors should be required to remove the entire contents of each receptacle, replace the cover and transfer the garbage to the removal vehicle in a water-tight receptacle. It should be required that garbage removal vehicles be at

Table XI

Material	Selling Price
Barrels	$0.1029 each
Bottles:	
Beer	0.0050 each
Milk	0.0050 each
Mixed	5.0000 ton
Sorted	$0.0025 to 0.0075 each
Syphon	0.1000 each
Glass	0.0023 lb
Jugs, earthenware	0.0050 to 0.0100 each
Metals:	
Brass	0.0660 lb
Cans	4.5000 ton
Copper	0.1150 lb
Iron	5.6000 to 8.1000 ton
Zinc	0.0300 lb
Paper	5.6000 to 5.7500 ton
Rags	12.0000 to 18.5000 ton
Rubber:	
Hose	0.0025 lb
Mixed	0.0400 lb

least half covered while being loaded and fully covered while in transit. All garbage from buildings where a contagious disease exists should be collected separately from other garbage and in vehicles specially provided for the purpose. The garbage collection contractor should also be required to remove dead animals from the highways and alleys immediately upon their presence being reported to him. In Philadelphia, garbage is collected every day in the thickly populated sections of the city, four times a week in the less thickly populated sections, and three times a week in the suburbs.

Reduction Method of Garbage Disposal at the Philadelphia Plant. The process of the reduction of garbage at disposal plant is as follows: The raw garbage is delivered at the central disposal plant by both vehicles collecting from the near-by territory and by scows which load at wharves on both the Delaware and Schuylkill Rivers to which vehicles haul from the more distant portions of the City. Mechanical chain pan conveyors transfer the garbage from the scows and from the bins into which the vehicles from an elevated platform unload their contents into elevated movable hoppers which can be discharged into any one of the several digesters. When a digester, which has a charging capacity of 10 tons has been filled and sealed, steam under a pressure of 75 lb is injected and the garbage is allowed to cook for a period of from 8 to 12 hr, depending upon the general character of the garbage being treated. At the termination of the digestion period, the cooked garbage is placed into hydraulic presses and by means of compression the solid and liquid matter is separated, the latter of which is conveyed to a central collector thru floor channels. The liquid matter, which, as it comes from the presses consists of a mixture of water, grease and more or less solids in suspension in the form of muck and silt, is passed thru a series of separating tanks, which separates by gravity the grease, which is then pumped into storage tanks to await shipment in tank cars or barrels. After the water is separated from the residual solid matter by means of evaporation the solid matter is stored for mixture later with the tankage. The solid product of the presses, which is known as tankage, is dried in revolving heated cylinders and then placed in revolving percolators which have a capacity of about 10 tons each. After the percolator is filled and sealed, gasoline is pumped thru the material. The gasoline dissolves any grease remaining in the tankage and is then drawn off into distilling tanks in which the grease is retained and the gasoline is driven off as vapor by means of steam heat and is conveyed to a condenser and finally to storage tanks. In order to prevent the loss of tankage grease this percolating or washing operation is repeated three or four times, if necessary. The tankage material is then discharged from the percolator, dried and screened and any foreign matter, such as glass, crockery or metals, removed. The screened tankage is mixed with the solid matter recovered from the liquid product of the presses and is again dried, after which it is ground, screened and stored or loaded for shipment. It will be noted that, except for the water content and a relatively small proportion of rubbish all of the by-products derived from the reduction of garbage are marketable and it may be stated at prices which yield a considerable profit over the plant operation costs. The grease consists principally of fatty acids and glycerol and these substances are utilized respectively in the manufacture of toilet and laundry soaps, soap powders and cleansers and glycerine, nitro-glycerine and dynamite. The tankage is utilized principally as fertilizer either as a whole or as a base from which are derived such materials as ammonia, ammonium sulphate, phosphoric acid, lime phosphate and potash.

Garbage Reduction Plant Operation Unit Costs. For the year 1914 the unit costs per ton of garbage reduced in the Columbus, Ohio, plant were as follows:

Item	Unit Cost	
Administration:		
Supervision	$0.197	$0.221
Clerical services	0.014	
Analytical services	0.010	
Labor:		
Firemen and enginemen	0.123	0.936
Operators	0.221	
Laborers	0.491	
Repairmen	0.101	
Operating supplies:		
Coal	0.314	0.535
Electricity	0.067	
Gasoline	0.109	
Miscellaneous	0.045	
Maintenance:		
Materials	0.091	0.128
Renewals	0.037	
Miscellaneous	0.039	0.039
Total		$1.859

The following operating materials were consumed per ton of garbage reduced:

Material	Unit of Quantity	Quantity Consumed
Coal	Ton	0.225
Electricity	Kilowatt-hour	4.480
Gasoline	Gallon	0.884

The net operating results per ton of garbage reduced were as follows:

Revenue thru sale of by-products	$3.085
Cost of operation	1.859
Net profit	$1.226

Unit Prices Received for Garbage Reduction By-Products. The average unit prices received during 1914 for the sale of the by-products of the Columbus Ohio, garbage reduction plant were as follows: Grease, $4.325 per 100 lb; tankage, $7.410 per ton. The selling price received for tankage was governed by the percentage of contained fertilizing elements as follows: Ammonia, $1.71 per ton; potash, $0.70 per ton; tri-calcium phosphate, $0.10 per ton.

Mechanical Analysis of Garbage. The mechanical composition of domestic garbage varies considerably during the several seasons of the year and to a more or less extent in different localities. The percentage of solids of tankage increases during the summer months while the percentage of grease increases during the winter months. Considering these variations, the following analysis will indicate the average composition of garbage during the entire year: Water, 75%; solids, organic, 15%; solids, inorganic, 6%; grease, 4%. The term organic solids includes all materials otherwise known as tankage, while the term inorganic solids is intended to include materials other than true garbage, such as cans, crockery, glass, etc, which must be removed from the tankage during process and are of practically no reclaimable value. While dead animals could possibly be included in the classification of garbage, yet in many cities only the smaller animals are so classified. The larger dead animals, such as horses and cattle, are usually sold by their owners to private rendering establishments. The average yield of dead animals when reduced is as follows: Water, 78%; grease, 5%; bones, 5%; other solids, 12%. The hides, especially those of the larger animals, are usually disposed of separately.

Chemical Analysis of Garbage. For a period of 1 year, during 1914 and 1915, the Bur. of Soils, U. S. Dept. Agric., conducted a rather extensive investigation to determine the chemical composition of garbage. Samples were taken in different localities and during every month of the year. In general, the results of the analyses of the individual samples seemed to indicate that the character of the population making the garbage did not influence the chemical composition of such garbage. The average results of all analyses conducted thruout the year on both raw and dry garbage were as given in Table XII.

Table XII

Material	Percentage of Weight	
	Raw Garbage	Dry Garbage
Moisture	73.85	None
Combustible	22.52	86.22
Grease	5.12	20.05
Ash	3.63	13.91
Nitrogen	0.71	2.87
Phosphoric acid, P_2O_5	0.39	1.52
Potash, K_2O	0.28	1.07

Chemical Analyses of Garbage Reduction By-Products. The average analysis of the by-products of the Columbus, Ohio, plant for the year 1914 were as follows:

TANKAGE: Tri-calcium phosphate, 8.08%; ammonia, 3.58%; moisture, 3.10%; grease, 1.20%; potash, 0.78%; other, 83.26%.

GREASE: Unsaponifiable, 2.910%; moisture, 1.520%; impurities, 0.131%; pure grease, 95.439%.

Classification of Dead Animals Removed from Highways. An interesting record covering a period of 5 years, 1911 to 1915 inc., of the kinds of dead animals removed from the highways in the District of Columbia, gives the following analysis which may be assumed to represent the average of conditions existing in the larger cities:

Table XIII

Kind of Animal	Number Removed	Percentage
Cats	58 463	63.7
Dogs	26 338	28.7
Horses	3 029	3.3
Rats	1 939	2.1
Chickens	961	1.0
Cows	14	0.1
Miscellaneous	1 012	1.1
Total	91 756	100.0

11. Equipment for Collection of Ashes, Rubbish and Garbage

Horse-Drawn Vehicles vs Motor Trucks. Horse-drawn vehicles are used in most cities for the collection of ashes, garbage and rubbish. Since 1915, however, some cities have tried out collection with automobile trucks and trucks hauled by tractors. There is no question but that on very

short hauls averaging 1 mile or under, the collection by horse-drawn vehicles is the most economical.

From experiments carried on in Philadelphia during 1916 it would appear that even with a haul of 2 miles the house to house collection of ashes by automobile trucks was not economical with a carrying capacity of under 10 cu yd. With a capacity of 10 cu yd or more the truck proved to be an economy over the horse-drawn vehicle. In studies made in Washington on the cost of collection of ashes during 1915 it was found that with an average haul of 1 mile that 50% of the time of the vehicle was consumed in loading, hence, unless the distance of the haul is considerably over 1 mile, it would not be an economy to collect with the motor vehicles.

The most economical method of collection would probably be a house to house collection by horse-drawn vehicles, the material to be hauled to a loading platform within the radius of ¼ to ½ mile of the collection district, and then dumped into automobile trucks to be hauled to the dump. However, a great deal of the street dirt is caused by the horses used in the street cleaning, collection of ashes, garbage, rubbish, etc, and this fact, together with the better appearance of the automobile trucks over the horse-drawn vehicles and the more desirable and flexible means of operating will eventually entirely eliminate the horse-drawn vehicle as a means of collecting the city waste.

Description of Equipment. Specifications should provide that all equipment either permanently or temporarily operated by the contractor should be of approved construction and fully conform to such requirements as the following:

Ash Vehicles. The ash vehicles must be strong and tightly constructed and be equipped with a one-piece durable canvas cover, supported on a frame, both of which are described in detail elsewhere in this Article. Metal ash vehicles shall be designed so that the top of the box will be not more than 4 ft 9 in above the ground and shall have a capacity of not less than 3.75 cu yd of material without piling, and so that the angle of the bottom of the wagon when dumping shall be not less than 30° with the ground.

Motor-Driven Ash Vehicles. Motor-driven ash vehicles shall be so designed that the top of the box will be not more than 5½ ft above the ground, and shall have a capacity of not less than 4 cu yd.

Rubbish Vehicles. The rubbish vehicles must be tightly constructed so as to prevent their contents spilling or blowing therefrom and must be equipped with a one-piece canvas cover.

Garbage Vehicles. The garbage vehicles shall have strongly constructed, water-tight, metal bodies, and be equipped with tightly closing metal covers.

Identification. Each vehicle shall bear on each side a blue enameled steel sign, lettered in white, containing the inscription, Bureau of Highways—D.P.W., followed by the designating number of the district and the serial number of the vehicle.

Ash Vehicle Covers. The inauguration of the use of dust-proof covers on ash collection vehicles has supplied a long-felt necessity, as the dust nuisance which exists during the loading of uncovered ash vehicles constitutes a serious inconvenience to the travelling public and also in the absence of covers more or less ashes are spilled or blown onto the highways. With a proper frame and cover, it is possible to partly cover the vehicle while being loaded and entirely cover it while in transit. Specifications for frames and covers might embody the following description of details of construction:

The ash vehicle cover frames are made of malleable iron pipe, 1 in in diameter and 1½ in angle iron. They consist of a ridge pole set at a height of 30 in above the upper edge of the flash boards and are supported on two loops, made of either angle or flat iron, the front loop set in a vertical position and the rear loop inclined outward. Both loops are attached to the body of the vehicle, the rear loop being reinforced with a diagonal brace. Both the iron pipe ridge pole and the diagonal braces at the rear of the wagon are fastened to the front and rear loops with rivets or bolts. The front and rear loops and the diagonal braces are bent to conform to the contour of the interior

sides of the vehicle and are attached thereto by means of bolts spaced 6 in apart. The entire frame is painted with three coats of gray paint. The canvas used in making the cover is that material known as No. 1 white duck, and of a weight determined on a basis of 18 ounces weight to 22 in in width of material per lin yd. The front curtain consists of one piece of canvas cut to the contour of the front loop and with enough extra material to pass completely around the loop frame so that it can be securely sewed together and kept permanently in place, or instead of this, metal-bound eyelets are provided along the entire edge of the curtain for tying it to the loop. The bottom of the front curtain entirely covers the face of the 2 by 6 in nailing board and is attached thereto with screw bolts inserted thru metal-bound eyelets in the curtain placed 12 in apart. The body cover is made of material 22 in in width, the sections being sewed together from a point 6 in outside of the front loop to the rear loop and carried over to form the tail curtain which consists of a separate section sewed to the main cover around the contour of the rear loop. All joints in the covers are provided with an additional reinforcing strip of canvas 1½ in in width, sewed with not less than 6 stitches to the in. At the junction of the ridge pole and the rear loop the section forming the tail curtain is slit down the center on an angle so as to provide an overlap of at least 8 in at the bottom, the corners being provided with metal-bound eyelets for tying the closed cover to the opposite sides of the vehicle. The cover is finished with a 4-in pocket stitched along the edge with 4 additional pockets stitched along the body of the canvas parallel to the edge and located at equi-distant points on either side of the ridge pole. Hickory battens, 6 in number, measuring 2⅛ by ½ in and of a length projecting 6 in beyond the front loop and extending to the outer edge of the rear loop, are inserted in these pockets. The ends of all battens are reinforced with a section of 8-ounce russet leather measuring 5½ by 4 in each, fastened with 6 rivets, 2 receiving the batten by being clinched thru the center. The cover is also provided with at least three 1-in leather straps, 1 in in width rivetted to the canvas for attaching the cover to the ridge pole. All other fastenings of the cover to the frame or body of vehicle are made thru metal-bound eyelets with the best quality ⅜-in sisal rope.

Painting of Equipment in Philadelphia. It is required that all vehicle equipment be painted at least three times during the year with standard paints, specifications for which are prepared by the Bureau of Highways and issued to the contractor. If three paintings do not preserve the permanency of the distinguishing colors, painting is required to be done more frequently. The colors of the painting required for the several types of vehicle equipment are as follows: Ash vehicles, gray; rubbish vehicles, red; garbage vehicles, brown. The equipment must be at all times maintained in a cleanly condition and the contractor is required to install adequate cleaning facilities within his stable or yard. The contractor is also required to present all vehicles and other equipment for inspection at such times and places as may be designated by the district engineer.

12. Administration and Organization of Waste Collection and Disposal

Municipal Force vs Contract Systems. In the interest of efficient service and economy and also to insure sanitary operating methods, it is specially desirable that the collection and disposal of ashes, rubbish and garbage be performed by municipal forces rather than under the contract system, and that the city own and operate disposal plants. The contractor for this character of service will naturally try to collect these waste materials at as small a cost as is possible, and consequently will not take pride in keeping the equipment up to the proper standard, nor will he employ as high a grade of labor as it is desirable to employ in this kind of work where the collectors are continually coming in contact with the householders. With respect to the disposal of garbage it should be borne in mind that, generally speaking, there is a profit of practically $1 a ton over operating expenses on every ton of garbage received at the disposal plant, exclusive of the cost of collection. It has also been demonstrated that a rubbish disposal plant can be operated in such a manner that it will pay the plant

operating costs, interest and depreciation charges and still produce a small revenue thru the sale of steam and electric power. But when this disposal work is performed by contract, the very nature of the work, which necessitates an enormous initial capital outlay for the plant and equipment, eliminates in itself all possibility of competition, whether the contract be for a 1, 5 or 10-year period. In the first place it would not pay to construct a plant for a 1-year contract. It should also be borne in mind, that if a contractor decides to bid on a 5 or 10-year contract, and will be obliged to meet competition at the end of that time, he will naturally make the contract price sufficiently high to include all operating, interest and depreciation charges, and yield a profit during the period for which he has the contract, and also to pay the interest charges on the invested capital during the time that the plant is likely to be idle due to his losing the next contract. It will be seen, therefore, that where there are two or more plants in existence in a community, the municipality must indirectly pay the interest and sinking fund, and possibly other charges on each of the plants instead of on only one as would be the case were the plant owned by the municipality.

Principles Governing the Organization of the Work. In working out a system of collection and disposal of ashes, rubbish and garbage the following purposes should be sought:

1. The consideration of the collection and disposal of household wastes, including ashes, rubbish and garbage, as an engineering function comparable in importance and possibilities of development with any other municipal engineering function.

2. The determination of the most economical and sanitary method of collection and disposal, including rubbish and garbage disposal plants for separation collection method and incinerating plants when the mixed collection method is determined upon.

3. The inauguration of all possible improvements in the collection and disposal methods with special respect to promoting economical, sanitary and safe operating methods and to preventing waste matter from littering the highways or creating unsanitary conditions or fire hazards at the disposal dumps or plants.

4. The consideration of the reclamation and sale of rubbish and the reduction of garbage and sale of the by-products as an asset by which the costs of its collection and disposal in a sanitary manner in disposal plants could be reduced to a minimum.

5. The installation of adequate report and record forms which provide complete and definite records of performances, which may be used to assist in the administrative control of the work.

6. The institution of a system for determining the unit and total costs of operating the service by which it may be possible to make comparisons of these costs with those for similar work in other municipalities.

General Organization Employed in Philadelphia, 1912 to 1917, under direction of the author while Chief of the Bureau of Highways and Street Cleaning. For the purposes of the collection of ashes, rubbish and garbage, which was accomplished under the contract system, the City was divided into eight districts whose boundaries are coterminous with the highway districts, except that in two instances a single highway district contains two service districts and in another instance two highway districts are considered as one service district. In each district the work was under the direct supervision of the district engineer who also had charge of street cleaning and the construction and maintenance of pavements. The numeri-

cal designation of the service districts were identical with those of the highway districts except in the instances where two service districts were included in the territory occupied by one highway district.

Collection Schedules. To insure that the collection may proceed in orderly sequence and at times that will be known to the public, each contractor was required to have personally served on the responsible occupant of every home and other building in his respective district at the beginning of each year an instruction and collection route schedule card, Fig. 4, indicating the days upon which collections will be made

☞ HANG THIS UP FOR REFERENCE

Notice to Housekeepers

GARBAGE

Will be collected between the hours of 7 A.M. and 6 P.M.

☞ Garbage must be kept separate from ashes and household waste.

Extract from Specifications

Kitchen garbage shall be called for and removed from all buildings, without charge to the occupants, on Mondays, Wednesdays and Fridays from January 1st to June 14th inclusive, and October 16th to December 31st, inclusive; and on Mondays, Wednesdays, Fridays and Saturdays from June 15th to October 15th, inclusive.

Garbage must be deposited in covered, water-tight vessels that can be easily and quickly handled by one man, and placed at points readily accessible to the garbage collector, who must remove the entire contents of said vessel.

Garbage from retail grocers and fish dealers shall be collected daily (except Sunday) in quantity not to exceed one (1) bushel from each store or stand.

Decayed vegetables or fruits from wholesale dealers is not considered as garbage to be collected by the Contractor, but the same shall be received and treated as other garbage, without cost to the *party delivering*, when delivered at the disposal works of the Contractor.

It is intended that waste paper and other refuse shall not be mixed with the garbage; but should any such matter be found with the garbage, it must be removed by the Contractor.

The Contractor shall remove all dead animals promptly, as they are found and reported. . . . All animals shall be removed in a manner satisfactory to the Director (of Public Works), and at all times covered during transportation.

Galvanized Garbage Cans (with cover), all of the same grade, are recommended as follows:

No. 02, capacity 6¼ gallons, price, about 85 cents.
No. 00, capacity 5¼ gallons, price, about 70 cents.
No. 000, capacity 4¼ gallons, price, about 55 cents.
No. 0000, capacity 3 gallons, price, about 35 cents.

The above-referred-to containers can be purchased from most all dealers in this kind of ware at approximately the prices named. The use of uniform and durable receptacles of the kinds described will have great influence on the sightly condition of our streets, effectiveness of collections, and also upon the health of the citizens.

All complaints should be addressed to

BUREAU OF HIGHWAYS

January 1, 1915 **Room 232 City Hall**

Fig. 4

and giving instructions to the occupant relative to the character of materials that may be classed as ashes, rubbish and garbage, and quantity of each class of material that will be collected and character of receptacles in which they should be placed. This card also contained extracts from the governing ordinances and requests that reports relative to the improper or non-performance of these services should be made to the Bureau of Highways. In certain districts, which were populated largely by

foreign speaking peoples, these cards are printed in four languages, namely, English, German, Italian and Hebrew. No changes were made in the scheduled collection routes unless approved by the Chief Engineer and provided that the affected householders should have received 24 hours' notice of the intended change. These schedules served as a guide to both the contractor's forces and the municipal inspection forces.

Frequency of Collections. The frequency of the garbage collections was based upon the actual requirements in the different sections of the City as governed by the density of population and the season of the year, while the frequency of the ash and rubbish collections was determined upon as a matter of fixed policy. The several classifications of collections were as follows:

GARBAGE: Class A, six collections per week, daily, except Sun.; Class B, four collections per week on either Mon., Wed., Fri. and Sat.; or, on Mon., Tues., Thurs. and Sat.; Class C, three collections per week, on either Mon., Wed. and Fri. or, Tues., Thurs. and Sat.

ASHES AND RUBBISH: Class D, one collection per week on a definite day according to a pre-arranged schedule.

Hours of Collection. All collections of ashes, rubbish and garbage were required to be made between the hours of 7 A.M. and 6 P.M. except that no ashes or rubbish were collected after 12 M. on Sat. In the interest of convenience to the public a further exception was made with respect to the collection of ashes and rubbish in the central business section, where the collections were made between the hours of 6 P.M. and 6 A.M. from April to Nov., inclusive, and during the months of Jan. Feb., March and Dec., between the hours of 3 P.M. and 10 P.M. On the following holidays no collections are made: New Year's Day, Fourth of July, Labor Day and Christmas.

Routine Inspection. The routine inspection of the collection and disposal of ashes, rubbish and garbage was performed by specially trained inspectors reporting to the respective district engineers. In general, each inspector was responsible for the work performed in a certain definite section of the district territory to which he was regularly assigned. He was required to verify and report the character and numerical strength of the force and equipment at work and to note the condition of the uniforms and equipment for which definite standards are provided.

Investigation of Complaints. See Art. 6.

Report and Record Forms. To assist in the efficient administration of the work the following report and record forms were provided: (1) Collection instruction and schedule cards, two cards, one each for garbage and for ash and rubbish collection respectively; (2) Inspector's daily reports, covering compositely the collection of both ashes and rubbish and garbage; (3) district engineers' daily reports, covering compositely the collection of both ashes, rubbish and garbage; (4) monthly unit cost data reports, two forms, one each for garbage and ash and rubbish collection; (5) complaint forms, two forms of distinctive colors respectively, one each for garbage and ash and rubbish collection complaints; (6) complaint register sheets.

Inspectors' Daily Reports. Similar to Inspectors' Daily Report described in Art. 6.

District Engineers' Daily Reports. Similar to District Engineers' Daily Reports described in Art. 6. See Fig. 4.

Contractors' Daily Reports. Each contractor was required to submit a daily report to the main office, in which he was required to report on the same kind of data as is required by the district engineer's daily report.

Comparison of Daily Reports. Each day the data shown on the respective daily reports for each district, of the district engineers and the contractors, were recorded by the main office on the comparison summary, one report form containing daily entries covering a period of one month. Any discrepancy discovered in the daily comparison of the data contained in the two reports was immediately investigated. At the close of the month, the records of the forces employed by the contractor were summarized and multiplied by the estimated unit costs to the contractor for each character of labor and equipment, which gave the probable total cost of the field operations to the contractor, which data was also used in connection with the compilation of the unit cost data report.

Unit Cost Records. Similar to Unit Cost Records described in Art. 6.

Labor and Uniforms of Employees. See Art. 6.

SNOW REMOVAL

13. General Considerations Relative to Snow Removal

Historical Development. There is probably no problem confronting a municipality which is at times of more vital interest to the public, and at other times so entirely forgotten than the problem of snow removal in the larger cities. During snow storms everybody is intensely interested even to the extent of advocating supposedly new or more expeditious methods of snow removal, but during the spring, summer and fall the general public entirely forget this important municipal function. Snow removal is distinctly an emergency problem and the more experience one has with this problem the more convinced one will be of the fact, that the human element is the dominating factor. There may be introduced scientific methods of snow removal that would operate successfully on a pleasant day, but which would be a complete failure in a storm when the conditions are such that none but the sturdiest type of laborer could work. Furthermore, the labor market is a factor that must always be considered. Some winters it is very easy to secure the services of all the laborers desired, while during other winters it is very difficult to get men for this work even with increased wages, so that any system that may be devised to cope with this problem will at some time or another fail unless the human element has been given due consideration. Until about 1912, the administrative arrangements and the working methods employed in connection with this work were very crude, this being probably due to the fact that snow removal was not considered seriously as an engineering problem. Prior to 1912 it was the custom in most cities to wait until a snow storm was over before beginning the work of removal. In other words, the city did not begin to dig itself out until after the storm had ceased. As a consequence, the highway traffic was often very seriously inconvenienced. Since 1912, however, very considerable study has been devoted to improving the organization and the general methods of snow removal, so that at present it may be stated that every detail of either organization, equipment or methods of operation that past experience has shown the need of have been amply prepared for and called into service. The highly satisfactory results produced thru the operation of the snow-fighting forces since 1912 has proven conclusively that the efficient administration of snow removal work is fundamentally a matter of preparedness based upon an exhaustive study of the requirements of the work and the establishment of a proper organization, the institution of a definite and adequate procedure, and the thoro instruction and drilling of the snow-fighting forces in the requirements of their respective duties.

The 1914 Snow Removal Conference. Snow removal in municipalities was the subject of more intelligent study during 1914 than probably ever before, which was evidenced by the Snow Removal Conference held that year in Philadelphia, at which were present representatives from 16 of the largest eastern cities. At this conference it was realized that the problem of snow removal must obviously be considered differently in different cities as its solution is dependent upon such variable elements as climate, population, width of streets, density and character of traffic, location of sewer systems, available disposal places and other local conditions, to say nothing of the financial policy of the municipality. It was deemed impossible to formulate anything but the most general suggestions, and yet it is found that even so vital a matter as the financial policy does not affect the main problem, except in the extent of the work.

Fundamental Principles of Snow Removal. In connection with the prosecution of snow removal work the general policy should be first, the

disposal of snow in the shortest possible time and at the lowest practicable cost; second, to eliminate the possibility of interruption of vehicular highway traffic during the snowfall by plowing the snow into windrows adjacent to the curbs; and third, to remove and dispose of the snow and ice from pedestrian highway crossings, vicinity of fire hydrants, gutters and sewer inlets and entire areas of congested business highways. One of the greatest difficulties in snow removal work is that there are seldom two storms presenting the same problem. For example, it is obvious that the difficulties of removal to be encountered in a blizzard carrying a considerable depth of snow are far greater than those encountered in a storm when the temperature is very mild and the snow is easily handled. There are innumerable considerations that present themselves in almost every storm that are somewhat different from every other storm. Sometimes it is possible to do far more satisfactory work panning and flushing than it is possible to do in the average storm. For instance, in one storm, preceding the snow a sheet of ice may be formed on the pavement. It would, therefore, be folly to remove all of the snow from this ice, as the snow is then the only means of footing for horses. The eccentricities of snow storms are limitless, but it would seem, all things considered, that the most reliable method for opening up the streets for traffic at the present time is to rely principally on the use of motor driven plows.

The Committee on Resolutions of the 1914 Snow Removal Conference Made the Following Recommendations embodying the underlying principles of snow removal work:

1. The plan of organization and the system to be employed should be worked out in advance of the snow season. This preliminary work should involve: (a) A plan of coöperation of all branches of the municipal government; (b) the formulation of a skeleton organization composed of all of the available city forces, such as engineers, inspectors, timekeepers, laborers and teams; (c) the division of the city into zones and the determination of a definite method of work for each zone. The various members of the organization should be assigned to these zones and the responsible officials familiarized with the duties expected of them. The character of work to be performed in the different zones may consist of merely the regulation of opening crosswalks and gutters and otherwise generally assisting pedestrian traffic and the run-off of snow, or it may consist in the complete removal of the snow from the streets. Owing to the general increase in motor traffic and the concentration of business in definite office districts and to the general public demand for increased urban facilities, the present tendency is to increase the scope of the work involving the complete removal of the snow from all main thorofares and business streets.

2. The work of removal should commence as soon as the snow has covered the pavements and the indications point to the storm continuing, and the operations should be carried on continuously. This as a principle, is successfully followed by street railways in the removal of snow from their track space, and by some cities.

3. The carrying capacity of the sewer system should be utilized as far as possible to get the snow away from the streets. The use of the sewers which reduces both the haul and handling to a minimum involves two operations: Namely, getting the material to the catch basins or manholes, and then putting the material into the sewers. The first operation can best be done by loading into wagons or trucks and hauling to suitable manholes, or by the use of scrapers or graders. The problem of getting the material into the manholes in the least time and with the least interference with the traffic opens up a field for consideration of the question of special forms and special locations of manholes, designed to be used solely for this purpose. The method of flushing the snow with fire hose into catch basins may have a limited application, but it is too unreliable to have any general value, as it depends on weather conditions.

4. When practicable, where there is only a small area to be cleaned, the work should be performed directly by the municipality by day labor. This method of operation is the most flexible and the most easily administered and it obviates the necessity of measurements and checking under the contract system. The work can also be performed by day labor in large areas by adopting the following method: The depart-

ment to advertise and go out into the open market and hire teams to haul the snow for so much per yard, the price to be determined upon by the department and to represent a fair estimate of the cost of the work and a fair profit. This, of course, would throw the work open to anyone owning one team, or a hundred or a thousand or more teams, depending upon the amount of work to be performed, and would not leave the department dependent upon any one or more contractors. In this method, as well as when the work must be performed by contract system, a method of measurement as simple and accurate as possible should be used. The practicability of having work done by the municipality will depend, among other things, on the immediate availability of an appropriation. It is essential for the proper conduct of the work, whether by day labor or contract, that appropriation for snow removal should be made in advance of necessity for the work.

5. Coöperation should be sought with the traction companies and use made of adjustable plows and sweepers to open roadways adjacent to street railway tracks at the time that the work of clearing the tracks is being carried on.

6. Efforts should be made to obtain the coöperation of the public and to instruct the householders in the method of removal of snow from private premises in such a way as to least impede the city's work. Where the sidewalks are of greater width than would be necessary to handle the reduced volume of pedestrian traffic, which can be expected after a heavy snow, the snow instead of being entirely cleared from the sidewalk and piled in the roadway should be left on the sidewalk near the curb line to be later removed by the city when opportunity presents itself.

7. The police force of the city should coöperate with the street cleaning forces and the services of patrolmen as inspectors should be utilized as far as possible. The police in particular should give attention to the enforcement of regulations governing the removal of snow from the sidewalks or from a portion thereof.

Snow Removal from Country Roads. Until the advent of the automobile, country roads were very little traveled in the winter, but it is not an exaggeration to state that at this time certain country roads are more important than a number of city streets and should be kept open for travel all the year round, not only as a means of passenger transportation, which is important enough in itself, but as a number of our inter-city highways are very extensively used by motor trucks for the transportation of merchandise and all classes of food.

As the motor truck transportation continues to increase, it is perfectly obvious that more attention must be given in the future to the removal of snow from these main highways, and this can be very readily taken care of by the use of snow plows attached to motor trucks. Their work, however, as in the removal of snow from city streets, would have to start as soon as the snow begins to make any appreciable headway, rather than waiting until the storm is over. Should this not be done, in many cases the snow will be so deep that it would be impossible to remove it with plows and traffic would be temporarily suspended.

The time is not far distant when it will not only be desirable but necessary to build snow fences on a number of our important inter-city highways at locations where the snow is likely to drift to any great extent.

Snow removal from the main country roads which are used for the transportation of merchandise, etc, will be in the future just as important a consideration in the upkeep of highways as the repair of pavements themselves, and will therefore become a very important function of state highway departments.

14. Practical Methods for the Removal and Disposal of Snow

The Three Principal Methods of Snow Disposal and their limitations may be briefly described as follows:

1. Plowing the snow to the side or center of the street by means of

automobile or horse-drawn plows, after which it is piled and then loaded into vehicles and hauled to dumps, which may be sewer manholes or rivers, and in some cases open lots.

2. PANNING, which consists of pushing the snow into sewer manholes by means of a specially constructed form of scraper, usually constructed of iron, which may be likened to a very large snow shovel.

3. FLUSHING the snow into sewer inlets or manholes. This is done by means of a hose or by running power flushing machines up and down the streets and forcing the snow to the gutter, following with a gang of men brooming the melted snow into the sewer inlets.

The first method of disposal, on which the main dependence is placed, plowing the snow and then piling and hauling it to dumps, is what might be termed the general method of disposal. This work starts when the snow begins to fall and plows should be kept continuously at work during and after the storm until all of the snow is removed from the streets.

The method of disposal by panning the snow into sewer manholes should only be considered as supplemental to the main method of carrying on this work by means of plows. It is not practical or possible to dispose of all of the snow by the panning method; in the first place it is impossible to get enough men to remove the snow by this method in a short enough time to avoid seriously interfering with the traffic; secondly, it is practically impossible to get an appreciable number of men to work on this method of disposal during a storm on a cold night, which is a condition to be met with in the greater number of snow storms.

The method of disposal by flushing cannot be carried on except when the temperature is above freezing and is therefore only supplemental to the main method of plowing, piling and hauling to the dumps.

Too much stress cannot be laid upon the fact that in order to successfully cope with the snow removal problem and open the streets to traffic at the earliest possible moment, the main dependence must be placed on the plows, supplementing this of course with the employment of as many men as it is possible to obtain to work on the panning method or pushing the snow into sewer manholes, and if the weather is warm enough, the employment of as many gangs and flushing machines as possibly can be used to dispose of the snow by flushing. In the plowing method of disposal it is of course desirable to have the dumps as close as possible and this means the universal use of sewers, dumping it into the manholes. Arrangements must be made where there is insufficient flow of water to connect the manholes with the water system. On Sundays and holidays in business sections of the city where factories are closed down, it will almost always be necessary to supplement the flow of water in the sewer thru a connection with the water system in order to have sufficient flow to carry off the snow.

Use of Sewer System. When the method used is that of plowing, shoveling into trucks or carts and hauling to dumps, the length of haul becomes of paramount importance, and it is obvious that the use of sewer manholes as dumps, with the sewer system to carry the material to the rivers, is the most economical method which can be used, as it reduces both the haul and the handling to a minimum. In PHILADELPHIA the sewer system has been used since 1912, but in some cities the authorities in charge of the sewer system have objected to the use of sewers as snow carriers.

This condition existed in NEW YORK CITY until exhaustive experiments were made by John T. Fetherston, Commissioner of Street Cleaning, New York City, and W. Goldsmith, Inspector of Public Works, Borough of Manhattan, in 1914. The following conclusions were a result of these experiments: (1) Under ordinary conditions

snow will melt in a sewer 300 ft from the point where it is dumped; (2) the theoretical number of B.T.U. necessary to melt snow checks the actual test in the sewer; (3) 2 cu yd per min was found to be the maximum rate at which it was possible to shovel snow into 24-in diameter sewer manholes; (4) there is much more heat in sewage than is necessary to melt within 300 ft all the snow that can be dumped into sewers; (5) syphon sewers carry snow away as well as others.

It is also found by experiment that: (1) Snow can be dumped by wagon-loads into sewers carrying 10 cu ft per sec or more; (2) panning can be employed where sewers have 3 cu ft per sec or more flowing in them, and where the velocity is greater than 1 ft per sec; (3) the snow can be shoveled into sewers having 2 cu ft per sec flowing in them, if the velocity is greater than 1 ft per sec.

In some cases the experiments show that where the velocity was great and the flow small, much snow can be carried away. For instance, at one location a sewer had a flow of 5.3 cu ft per sec, the velocity, however, being 10 ft per sec, yet with this slight flow the sewer made an excellent dump.

In referring to the use of sewers for snow disposal, at the conference on snow removal held March 8, 1916, A. E. Kalbach, Deputy Street Cleaning Commissioner, Borough of the Bronx, New York City, stated: "Until the winter of 1914–15 extensive use had not been made of sewers for the removal of snow. Water transportation has always been cheapest, and by using the artificial waterways of the city, melted snow reaches the same destination as that which is hauled to and dumped into the river, and with the most expensive steps of the latter operation eliminated.

"In February, 1914, the proposition for the complete utilization of sewers was advanced. The general plan proposed was that snow should be removed from the streets by men equipped with regulation pan scrapers who would shovel snow into the sewer manholes while the snow is falling and as fast at it falls, and that such plan would be successful provided: (1) That flow in sewers be of sufficient depth; (2) that the remuneration to the emergency force be sufficient to obtain the men in character and number required to perform the work.

"The advantages of such a system were pointed out to be: (1) Economy in disposal of snow; (2) economy to all persons engaged in transportation, by elimination of traffic congestion due to snow-blocked streets; (3) cleaner streets, because department vehicles could adhere more closely to their normal schedules, and thus prevent the dumping of household refuse on the snow piles in many sections of the city when the regularity of the service is upset, owing to street conditions and traffic congestion.

"Upon the adoption of the general plan a survey of sewers was made to determine the depth and velocity of sewage in 1098 miles of sewers. The information was plotted on maps. Snowfall data for the previous 46 years were collected and analyzed. Weather conditions were studied and department employees instructed to record observations of the barometer, wet and dry thermometers, force and direction of wind, cloud forms and directions from which they were moving, to be used in making weather predictions.

"The result of the first season's work was satisfactory. Tables used in this paper are taken from the report of Commissioner Fetherston to Mayor Mitchel, comparing work on previous plans of contract work on yardage and area bases as compared with the combination of snow fighting and snow removal. The rate of removal was double the best record obtained in the season of 1913–1914, which itself was double the best previous record on the truck system of removal. The cost per cu yd, 12.1 cents, compared with the average cost of 57.3 cents in the six preceding winters, and with the lowest record in that period of 33.7 cents.

"The speed of snow removal by snow fighting in 1914–1915 more than doubled the best previous record, and more than trebled the average record for the period of 1902–07, when the area basis of measurement was employed. The cost per cubic yard of snow removed by use of sewers in 1914–1915 was equal to one-fifth the average cost of removal on the area basis, and one-fourth the cost of the lowest record made from 1902 to 1907."

It will be noted in the following table that the cost in 1914–1915 in New York was 12 cents per cu yd. This was largely due to the removal of 3 858 912 cu yd of snow at 7 cents per cu yd by panning or shoveling the snow into sewer manholes, and a large percentage of this work was done on Easter Sunday in April, 1915, when the weather was very mild.

Table XIV.—Comparison of Annual Snow Work Data

Winter	Number of Working Storms	Depth Working Storm Inches	Days Work	Cubic Yards Removed	Total Cost	Cost per Cubic Yard	Average Cubic Yards Removed per Day
1907–08......	4	23.0	45	1 125 447	$413 556	$0.367	25 009
1909–10......	3	30.0	44	1 873 236	1 405 628	0.750	42 573
1910–11......	5	23.7	46	3 625 716	1 470 904	0.560	57 081
1911–12......	5	17.7	39	1 590 235	870 389	0.547	40 775
1912–13......	1	11.8	8	496 047	245 623	0.495	62 006
1913–14......	3	38.2	43	5 180 825	2 473 343	0.477	180 484
Averages......	3.5	24.1	37.5	2 148 584	1 146 574	0.533	57 296
1914–15......	3	22.4	16	4 318 481	533 892	0.121	269 905

In Philadelphia the snow and ice removed from the highways are disposed of by being dumped either into the sewer thru manholes, many of which have been especially constructed for the purpose, or directly into either the Delaware or Schuylkill Rivers, either at the wharves or thru manhole openings in bridge floors. Where the normal flow in a sewer is insufficient to quickly carry away the dumped snow and ice, a water jet has been installed which serves to increase the flow and this flushing is regulated by the inspector stationed at the dumping station. Considerable difficulty has been experienced with sewer manholes which are located between the rails on heavy traffic trolley lines, and arrangements are being made where sewers are of sufficient depth to construct sewer manholes on the shoulder with chutes to the sewer.

Snow Plow Outfits. Aside from the horse-drawn plows, which are ordinary road scrapers, commercial motor trucks can be equipped with plows. These are of two types, one has the plow attached to the front of the truck and the other simply hauls a road scraper. Experience has demonstrated that those plows attached to the front of a motor are more efficient in every way, particularly with a wet, heavy snow than the plows hauled by trucks, for the reason that the road scraper is comparatively light and tends to swing away from the snow, whereas this difficulty is not experienced when the plow is on the front of a heavy motor truck, particularly when the truck body is loaded. The driver's seat on the motor plow should be closed in order to keep him at work at all times, even under the most trying conditions. The specification requirements for this type of plow are as follows:

Automobile Plow Outfits. All automobile plow outfits must consist of a motor truck of not less than 4 tons' capacity and in front of which must be securely fastened an adjustable plow blade set at an angle of about 45°, and not less than 10 ft in length and 1 ft in depth; or, a motor truck of the same capacity, hauling a scraper with a similarly constructed plow blade. Each such plow outfit must include a driver and one extra man.

Horse-Drawn Plow Outfits. When the use of horse-drawn plow outfits is permitted they must consist of a plow or road scraper of a type to be approved by the Chief Engineer, drawn by 4 horses and manned by 2 drivers and 1 operator.

Hauling Vehicles. All vehicles used for snow removal should be required to have an ultimate carrying capacity of at least 2 cu yd. The box structure should be so enclosed on at least three sides as to give the vehicle a total full load capacity of at least 2 cu yd, and to prevent the spilling of the contents. The inspector should be required to measure and compute the cubical contents of each type of hauling vehicle for which he issues loading tickets and to indicate this capacity on the ticket by punching or marking out in indelible pencil the proper yardage indication.

Method of Determining Quantity of Work Performed. The number of cubic yards of snow and ice removed and disposed of by a contractor should be determined in the following manner: For each vehicle loaded to its rated capacity the loading inspector should issue to the driver of the vehicle a loading ticket indicating by cubical measurements the contents of the vehicle. After the vehicle's full-sized load has been delivered to the assigned authorized dump and properly dumped and disposed of the dumping inspector should issue to the driver a dumping ticket in exchange for the loading ticket which the driver surrenders to the dumping inspector.

Snow Removal from Sidewalks. One of the weak features in snow removal work is that the snow is very often removed at night from the roadways and the following morning all of the snow from the sidewalks is shoveled into the street that has already been cleaned. In order to cope with this situation in Philadelphia, thru the coöperation of the Police Department a regulation was introduced which required that the occupants of homes and other buildings thruout the city should, 6 hr after the snow had ceased to fall, remove it from the footways abutting their property, leaving a passageway at least 4 ft in width and piling the snow on the footway between the curb and a line 3 ft within the curb. This does away with the practice of shoveling snow from the sidewalk into the street after it has been cleaned of snow.

Use of Cinders on Slippery Roadways. On or before Nov. 1st of each year cinder boxes should be placed on the highways at the locations where traffic is heavy and it is known that slippery conditions will develop. These boxes, which should be kept filled with cinders at all times, should have a capacity of not less than 14 cu ft. They should contain the lettering, Cinders for Slippery Pavements. The cinders should be spread upon the highways just as soon as dangerously slippery conditions develop, whether or not the snow and ice have been entirely removed from the roadway surface. When necessary, extra loads of cinders should be hauled to the locations where needed, distributed directly upon the highway from the hauling vehicles by a mechanical spreading device.

15. Experimental Methods for the Removal and Disposal of Snow

Classification of Methods. Of the experimental methods none have thus far been found to be practical for snow removal work in municipalities. These devices and methods include asphalt surface heaters, elevator grading machines, compressing boxes, special sewers under the curbs and various melting devices, such as steam pipes under the sidewalk and roadway. A number of investigations and experiments have been conducted to determine the practicability of removing and disposing of snow by mechanical melting methods. The more recent investigations were outlined by Fetherston (21d). Extracts covering the important experiments described are included as indicated by references. Up to 1917 no mechanical melting process has been found to be economically practical.

Melting Snow by Steam Methods (21d). Preliminary to the investigation of the melting by steam method of snow removal and disposal it was necessary to determine the latent heat and density of snow as it falls. A series of experiments were accordingly conducted during 1915 by Otto H. Klein, Director of the Standard Testing Laboratory, New York City, with the following results:

Latent Heat of Snow as it Falls. Four determinations were made, giving values of 80.8, 81.7, 79.6 and 81.7 calories, with an average of 80.9 calories, equivalent to 145.6

B.T.U. This represents a very fair agreement with the theoretical values of 80 calories, or 144 B.T.U. The factors influencing this result include: (1) Initial temperature of the snow; (2) percentage of water in the snow; (3) final temperature of the mixture. With the exception of the second factor, the first and third may be readily controlled by, first, the use of an accurate thermometer graduated to hundredths of a degree, and second, having two men perform the experiment, with one of them constantly at the calcrimeter taking readings; in this way an accurate estimate of the difference in temperature may be made. Furthermore, if the snow can be obtained at low temperatures it is safe to assume that it is dry and contains no free water.

Density of Snow as it Falls. Four determinations were made on the snow as it fell, and the following figures for the density were obtained:

Number of Determination	Density	Corresponding to Lb per Cu Ft
1	0.13	8.1
2	0.14	8.8
3	0.17	11.3
4	0.11	6.9

The temperature of the air at the time of the experiments averaged 0.6° C (35.8° F). The density of snow is dependent upon three conditions: (1) The compactness of the snow crystals; (2) the water content; (3) the content of foreign bodies. With regard to the presence of foreign bodies, the density of snow will vary with the locality and may become as high as 1.31. It is therefore obvious that the density of snow is a variable quantity. According to J. C. Trautwine, the weight of 1 cu ft of freshly fallen snow will vary from 5 to 12 lb, depending upon the humidity of the atmosphere; and 1 cu ft of snow when moistened and compacted by rain will vary from 15 to 50 lb. Ludwig Schaller in "die Belastung der Baukonstruktionen durch Schnee," found the density of very dry clean snow to be 0.12, while that of very dry snow compacted by wind was 0.17; under other conditions (moisture, etc) it may become 0.41, 0.46, etc.

Relation of Latent Heat to Varying Degrees of Density. Determinations made on loose freshly fallen snow and also on packed snow indicate no difference in the latent heat. The latent heat naturally depends upon the mass of the snow, but has no connection whatever with volume *per se* and therefore only as far as mass concerns the density, will the latter determine the latent heat of the snow. The only important factor to consider in this connection is the water. With an increase in the percentage of the water in the snow, the density increases, and the latent heat decreases.

Amount of Dust Entrained in Snow as it Falls. As was mentioned above, the presence of foreign bodies in the snow will obviously depend upon the locality. The figures obtained show that the samples of snow collected at the roof of this laboratory contained from a trace to 0.05 % entrained dust. In every snowfall, after the snow has been falling for a short period, the atmosphere is freed of impurities, therefore the first part of the fall contains the greater part of the atmospheric dust. Hence the condition of the atmosphere is another factor to be considered.

Flush Test. This test was made in order to determine the approximate quantity of water necessary to flush a definite quantity of snow, and the following experiments were made. In the first case, 2400 grams of snow at 0.2° C (32.3° F) required 26 640 cu cm of water at 9° C (48° F) to flush it off; while in the second case 2350 grams of snow at 0° C (32° F) required 34 840 cu cm of water at 8.3° C (47° F) to flush it off. Ordinary tap water was used.

The ratio of water to snow is $\frac{28\,640}{2\,400} = \frac{148}{1}$ in the first case, and $\frac{11.9}{1}$ in the second case. These values have little significance, however, for a great deal depends upon the temperature of the water used.

Relative Weights of Snow and Ice. Some years ago a number of experiments were performed at Kingston, Canada, on the relative bulks of snow and ice. The results which are recorded (27) showed that the average temperature of 1 cu ft block of ice was − 18° C (0° F) and its weight was 57 lb. The block was allowed to melt at 11° C (52° F) and yielded ⅞ cu ft water or 1512 cu in weighing 54 lb. One cu ft of snow was then taken up and compressed. Its average temperature was − 7° C (19.5° F),

weight 63 lb, 14 ounces, and when melted at 11° C (52° F) yielded 1728 cu in water weighing 1021 ounces or 63 lb, 13 ounces.

Snow Melting with Portable Steam Boilers. Accepting the latent heat of snow at 144 B.T.U. the following data was compiled by Fetherston. It was assumed that the snow melting equipment would consist of portable steam boilers with flexible steam hose connections operated by laborers. It was also assumed that the water produced by the melted snow would run thru the gutters to the sewer inlets without freezing.

Table XV.—Data on Snow Melting by Portable Steam Boiler

HEAT REQUIRED PER POUND OF SNOW:	
Latent heat of snow	144 B.T.U.
Heat required to raise temperature from —6.7° to 0° C (20° to 32° F)	12 B.T.U.
Heat required to warm water 24° C (76° F)	44 B.T.U.
Total heat required to melt snow and run water to sewer basin	200 B.T.U.
WEIGHT OF SNOW PER CUBIC FOOT:	
Minimum weight newly fallen snow	5 lb
Ordinary weight newly fallen snow	12 lb
Weight of snow in trucks after handling	30 lb
Assumed average weight city snow	16 lb
SNOW MELTED PER POUND COAL:	
1 lb steam at 50 lb pressure contains	1174.00 B.T.U.
1 lb steam, no waste, will melt $\frac{1174}{200}$ or	5.87 lb snow
In portable boiler assume steam delivered per pound of anthracite coal	6.00 lb steam
Hence snow melted per pound of coal would be 6 × 5.87	35.22 lb snow
VOLUME OF SNOW MELTED PER POUND COAL:	
Assumed weight of snow per cubic foot	16 lb
Hence 1 lb coal (without waste of steam) will melt $\frac{35.22}{16}$	2.2 cu ft
AREA CLEARED OF SNOW BY STEAM FROM 1 LB OF COAL:	
Assume 6-in snowfall:	
1 lb. coal will melt, without waste of steam, $\frac{2.2}{0.5}$	4.4 sq ft
Assume 12-in snowfall:	
1 lb coal will melt, without waste of steam, $\frac{2.2}{1}$	2.2 sq ft
SPEED OF MELTING:	
Assume 70-h. p. portable boiler on wheels, allow 25 sq ft grate area and 12 lb of coal burned per sq ft of grate per hr or 300 lb coal per hr.	
Note: A 70-h. p. boiler on wheels will weigh 15 000 lb without water.	
Area cleared of snow per hour:	
6-in snowfall, 300 × 4.4	1320 sq ft, 146 sq yd
12-in snowfall, 300 × 2.2	660 sq ft, 73.3 sq yd
Volume melted per hour:	
300 lb coal × 2.2 cu ft	660 cu ft
Equivalent, cu yd	24.44
COST PER HOUR, 70-H. P. PORTABLE BOILER AND CREW:	
Coal at \$6.25 per ton = $\frac{300}{2000}$ =	\$0.9400
Horses, 4 at \$1.50 per 8-hr day	0.7500
Driver, 1 at \$2.50 per 8-hr day	0.3125
Engineer, fireman, 1 at \$4.50 per 8-hr day	0.5625
Laborers on steam hose, 2 at \$2.50 per 8-hr day	0.6250
Total, no fixed charges	\$3.1900

Cubic yards melted per hour, no steam wasted	24.4
Cost per cubic yard, original snow	$0.13

Application of Estimates to Conditions:

In Manhattan, Bronx and Brooklyn, the street area scheduled for removal was	22 410 446 sq yd
Number of 70-h. p. boiler hours required to clear this area:	
After 6-in snowfall	152 764
After 12-in snowfall	305 736
Number of 70-h. p. boilers working 24 hr per day required to clear snow:	
For 6-in storm, 6 days; For 12-in storm, 12 days	1 061
Cost of 1061 boilers at $700	$742 700
Minimum charge for interest, depreciation and storage per annum on above machines would amount to 15%	111 405
For average year, 4 storms of 6 in are removed, 576 hours per year boiler in use, thus the overhead per hour per boiler would be	18 cents

Actualities:

Allow 50% efficiency in the application of steam from hose on street, this is believed to be high, then the cost per cu yd of original snow would be 26 cents without fixed charges. With fixed charges 27.6 cents.

For comparison with truck haulage cost in Manhattan, 47 cents per cubic yard, the shrinkage in original snow would amount to at least 50%; thus cost of melting by steam would be 52 cents per cu yd without fixed charges, or 55.2 cents with fixed charges.

Coal Consumption of 1061 Boilers:

To clear 6-in storm in 6 days	22 915 tons
To clear 12-in storm in 12 days	45 860 tons

To keep the boilers supplied will require the delivery of 159.1 tons of coal per hr at 1061 localities in the city.

The Ashes to be Removed from Boilers:

After 6-in storm	2 292 tons
After 12-in storm	4 586 tons

Cost of ash removal not covered in estimates, but would amount to $1 per ton, and require the services of 382 city carts to remove ashes in 1 day after a 6-in storm, or 764 carts for 1 day after a 12-in storm.

Snow Melting by Steam Generated by Coke and by Naphtha Furnaces. During 1895 actual tests were made in New York City by C. D. Pollock under the direction of Commissioner Waring of the Street Cleaning Department.

Table XVI.—Snow Melting Test Data

STEAM SNOW MELTING TEST, SUNDAY, FEB. 17, 1895

Franklin St. basin, 140 ft east of Broadway, 8-hr test.

1	Engineman,	$3.50 for 10 hr	$2.80
1	Assistant,	2.25 for 10 hr	1.80
1	Boiler,	5.00 for 10 hr	4.00
1¾	Chaldrons coke at	4.00	7.00
2	Laborers at basin,	2.00 for 8 hr	4.00
3	Carts,	3.50 for 8 hr	10.50
			$30.10

Result: Melted 62 loads snow at 28½ cents per load. Does not include piling and loading.

STEAM SNOW MELTING TEST, MONDAY NIGHT, FEB. 18, 1895

Franklin St. basin, 9 hr test.

2 Engineers,	$3.50 for 10 hr	$6.30
1 Assistant,	2.25 for 10 hr	2.03
2 Boilers,	5.00 for 10 hr	9.00
3½ Chaldrons coke at	4.00	14.00
3 Shovelers at basin,	2.00 for 8 hr	6.75
6 Carts,	3.50 for 8 hr	15.75
		$53.83

Result: Melted 104 loads snow at 51.8 cents. Does not include piling and loading.

TEST OF CUNDELL'S NAPHTHA SNOW MELTING MACHINE

Night of Feb. 11, 2 blocks on Worth St., from Broadway to West Broadway.

Time of first machine, 4 hr, 57 min
Time of second machine, 4 hr, 12 min } Total, 9.15 hr.

20 Barrels naphtha used in 12¼ hr, 1.6 an hr at $3.75 per bbl:

Cost of naphtha per hr, $6 for 9.15 hr		$54.90
15 Laborers at $2.00	$30.00	
1 Foreman	2.50	
1 Engineer	3.50	
1 Assistant Engineer	2.00	
Cost of Labor, 8 hr	$38.00	
Cost of Labor, 9.15 hr		43.46
		$98.36

Two hundred and sixty-four loads of snow in D. S. C. carts were removed from Leonard St., between Broadway and West Broadway and Temple Court on night of Feb. 12th, 1895. Assuming the same quantity of snow to have been taken from Worth St., then the cost per load was about 37 cents.

Snow Melting by Electric Method. During Feb., 1914, the New York Edison Co., New York City, carried out a series of experiments on melting snow by electric power with the following results:

Table XVII.—Data on Snow Melting by Electricity

Test	Cu Yd Snow Melted	Elapsed Min	Time Hr	Electrical Data				Temperature of Discharged Water	Rates	
				Volts	Amps	Kw	Kw-hr		Cu Yd per Hr	Kw-hr per Cu Yd
1...	1	7.25	0.121	236	1017	240	29.0	....	8.3	29.0
2...	9	84.00	1.400	242	1100	267	345.3	75° F	6.4	38.4
3...	2	17.00	0.284	240	1010	avg 242	avg 68.7	39° F	7.0	34.3
4...	2	36.00	0.600	147	717	107	64.2	33° F	3.33	34.1

The snow which was melted weighed 35 lb per cu ft and it was estimated that with more efficient apparatus the current consumption could be reduced from ⅓ to ½. At a cost of 1½ cents per kw-hr, the charge for melting would approximate 45 cents per cu yd when dealing with snow weighing 35 lb per cu ft. The cost of gathering and handling snow would still have to be added to the melting expense, also the fixed charges. If hydrant water were not available for supplementing the normal flow of sewage, the use of electric melters might be advantageous, but it is doubtful if this method would compete with direct sewer disposal.

Snow Melting by Gas Heat Method. So far as known no extensive investigations relative to the practicability of utilizing gas heat for removing snow have been conducted in this country. In referring to this matter, however, Fletcher (22) states that: "The plan of melting by coal gas is absurd. Six inches deep of average snow, when

melted, becomes 1/6 in depth of water, 24 sq ft of which will weigh 62½ lb or 23.4 lb per sq yd. At this rate the snow on one mile of street 20 yd wide would, if 6 in deep, weigh 823 680 lb or 363¾ tons. The heating power of London gas is 660 units per cu ft and we may assume that 500 units could be utilized. It has been proven that 1 lb of snow at the freezing point requires 150 units of heat to melt it and raise the temperature of the water obtained to 4.4° C (40° F) and this effect would be produced on 3⅓ lb snow by the consumption of 1 cu ft of coal gas. From the above data, it will be found that to melt the snow in the assumed mile of street would require the consumption of 247 000 cu ft of gas, costing at 3 s ($0.73) per 1000 cu ft, a little over 37 lb, or at the rate of 3256 lb per sq mile. Even if we were to assume that the cost of gas and labor was not prohibitive, the fact that the ground itself is usually colder than 0° C (32° F) must be considered, and the ground would also have to be warmed or a thin surface of glassy ice would remain after the snow was removed; this would also condemn the project."

Steam Pipes Under Sidewalks and Roadway. There has been suggested the installation of steam pipes under the sidewalks and roadway, connected with central heating plants.

General Considerations. No estimate is available of the cost of such an installation. The installation of a system of heating which would insure the temperature of the pavement remaining at say 27° C (80° F), while the temperature of the air was as low as −18° C (0° F), would serve to prevent any accumulation of the snow and the snow problem on city streets would be solved in an ideal way. Some such arrangement may ultimately be used on certain streets in large cities, but the difficulties in the way of such a scheme are many. It would be necessary to install one or more mains, depending on the width of the street, with laterals not more than 4-ft centers from house line to house line. This would mean that either the entire pavement would have to be removed or that it would be necessary to wait until the street was repaved before installation. With such a network of pipes on the surface, the difficulty of installing new underground structures is apparent. The question of taking care of the large quantity of condensed steam would also be a problem in itself. As there is scarcely a building in the center of a city which is not equipped with a heating plant, some arrangement or legislation might be had to compel property owners to supply with steam the pipes directly in front of their properties, this to be supplemented by the heating plants controlled by the city. The cost and impracticability of installing such a system on a large scale, on account of the numerous difficulties to be encountered would not seem to warrant serious consideration, but in 1950 or later, when there is a possibility of dreams of the ideal city becoming a fact, this method is recommended for consideration in connection with future city planning.

Portable Car Equipped with Steam Pipes. The Penn. Co. has been using several snow melting devices on their Philadelphia Terminal Division. One of these devices might be made particularly applicable to municipal work; the others are peculiar to railroad work, such as the melting of snow in switches with burning oil, and the disposal of snow in snow melting pits located in their yards. Also a device on a locomotive by which the snow is blown away from the tracks with live steam sent thru a pipe located between the wheels and near the tracks, but the idea of equipping a car with steam pipes for melting snow is one which is worthy of attention for municipal work.

Method of Use. The R. R. Co. uses a gondola car, the inside dimensions being about 38 ft 8 in in length by 9 ft 3 in in width and 3 ft 9 in in depth, about 1 ft below the top of the car being a false bottom forming a pan, which is used for the steam pipes and for storing hot water. The steam pipes are of various lengths and are open at the ends. This arrangement distributes the steam directly over the entire pipe. The first snow is melted by the steam and in a short time the accumulated water is boiling. The snow is then melted by the boiling water. In the center of the pan is a small manhole, 11 in high, thru which the water overflows to the lower part of the car which is about 2 ft 6 in in depth, and is used for the storing of the accumulation of snow water. The amount of snow that can be melted in the car before letting the water out is equivalent to approximately 25 carloads of the type of car generally

used by them for this purpose, depending somewhat upon the compactness of the snow. With 20 men this car has been filled with water three times a day of 10 hr. The water can be dumped at any drain or pit, or when the ground is frozen, at any point where it will readily drain away. A single car has a distinct advantage over a long train in congested districts. It also frequently happens that a car can be emptied at points where there is snow to be loaded. In this way more snow is being disposed of while the car is emptying itself. Naturally, the best results are obtained by handling the snow while it is new and before too much dirt is mixed with it. The car has been in use for two winters and in 1916–1917 was used continuously after each snow storm until the accumulation of snow had been removed. During all the snow storms of the 1916–1917 winter the R. R. Co. did not haul one shovelful of snow from the Penn. Terminal yard and considering the actual necessity of keeping these tracks practically entirely clear of snow, particularly around switches, the R. R. Co. feels that this shows conclusively the advantages of the various melting devices which they are using.

16. Administration and Organization of Snow Removal

General Organization. As in any other similar character of work it is necessary to have a very definite order of procedure in the general organization under which the work is performed, and the following details of such an organization in Philadelphia, under the direction of the author as Chief of the Bureau of Highways and Street Cleaning from 1912 to 1917, will give a general idea of some of the essential factors necessary to properly control this work:

In Philadelphia the snow removal and disposal work was performed by the following regular and emergency forces: (1) Emergency snow re-

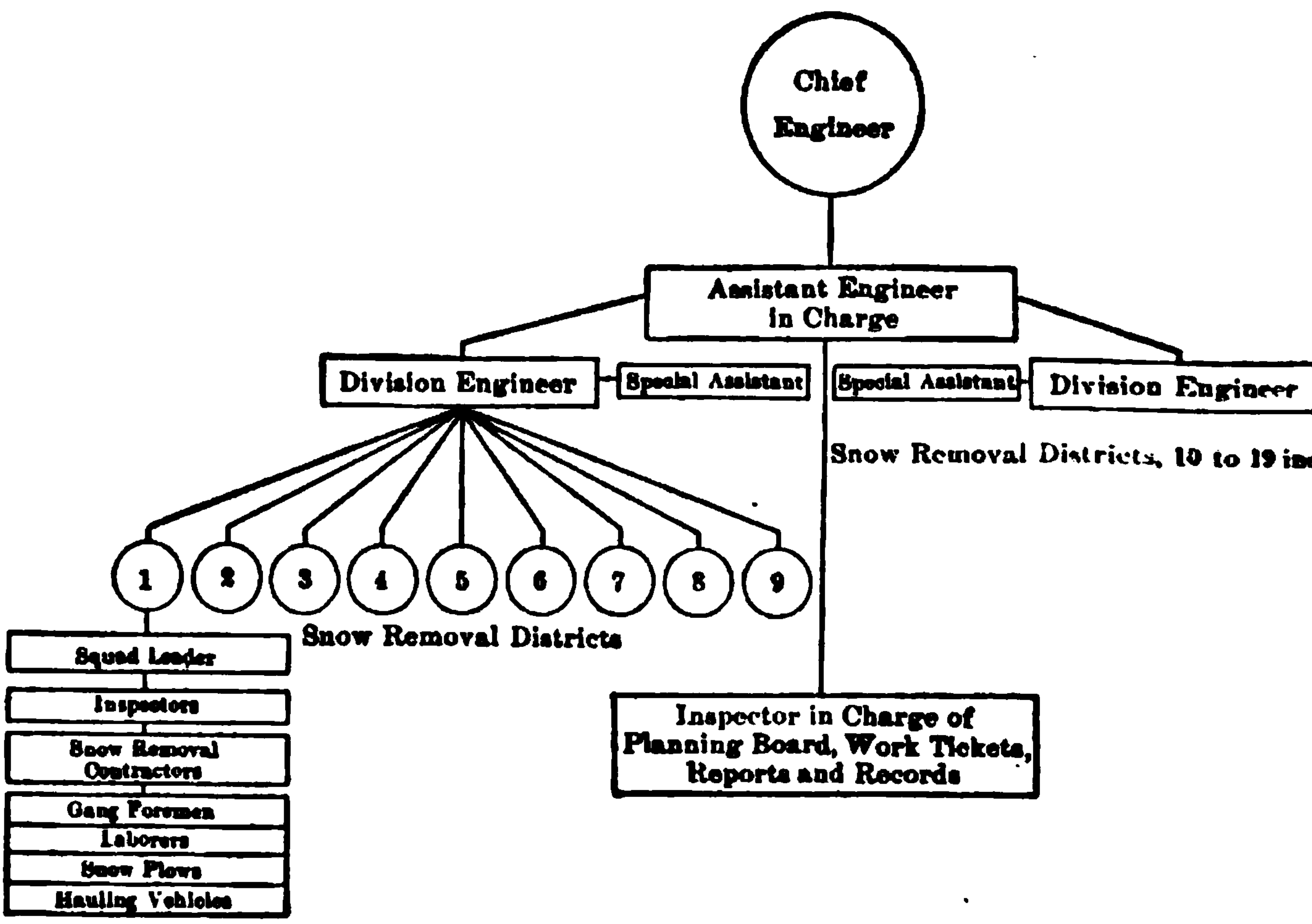

Fig. 5. Organization Chart of the Routine Snow Removal Work in Residental and Outlying Business Sections of Philadelphia

moval laborers and contractors' forces; (2) regular street cleaning forces; and (3) regular municipal labor forces.

The cleaning of snow and ice from the entire area of highways in the central business section, which is divided into 19 districts, was done by the emergency snow removal contractors' forces, emergency laborers and

the regular street cleaning and municipal labor forces under the direct supervision of the Chief Engineer assisted by a provisional organization composed of special assignments from the entire engineering and inspection force. That portion of the snow removal work which was performed jointly by the regular street cleaning forces and the municipal labor forces under the direct supervision of the district engineers and their regular subordinate organizations, included the removal of snow and ice from highway crossings, gutters, sewer inlets and the vicinity of fire hydrants thruout the city; and, after this work was finished the cleaning of the entire areas of certain selected highways in the important business sections in the several respective districts. A large force was also employed opening up the suburban and country roads, where the drifts often completely block traffic. The organization details of both the regular district forces and the provisional central forces are indicated respectively on charts, Figs. 5 and 6.

The Snow Alarm or Mobilization of the Snow Removal Forces. The main idea in a snow removal organization is preparedness. The snow alarm, or preparedness in the work of snow removal as it was generally termed in Philadelphia was an innovation introduced by the writer when Chief of the Philadelphia Bureau of Highways and Street Cleaning and was operated from 1912 to 1917. The conception and operation of the snow alarm in Philadelphia was one of the unique improvements which resulted in greatly benefiting the community.

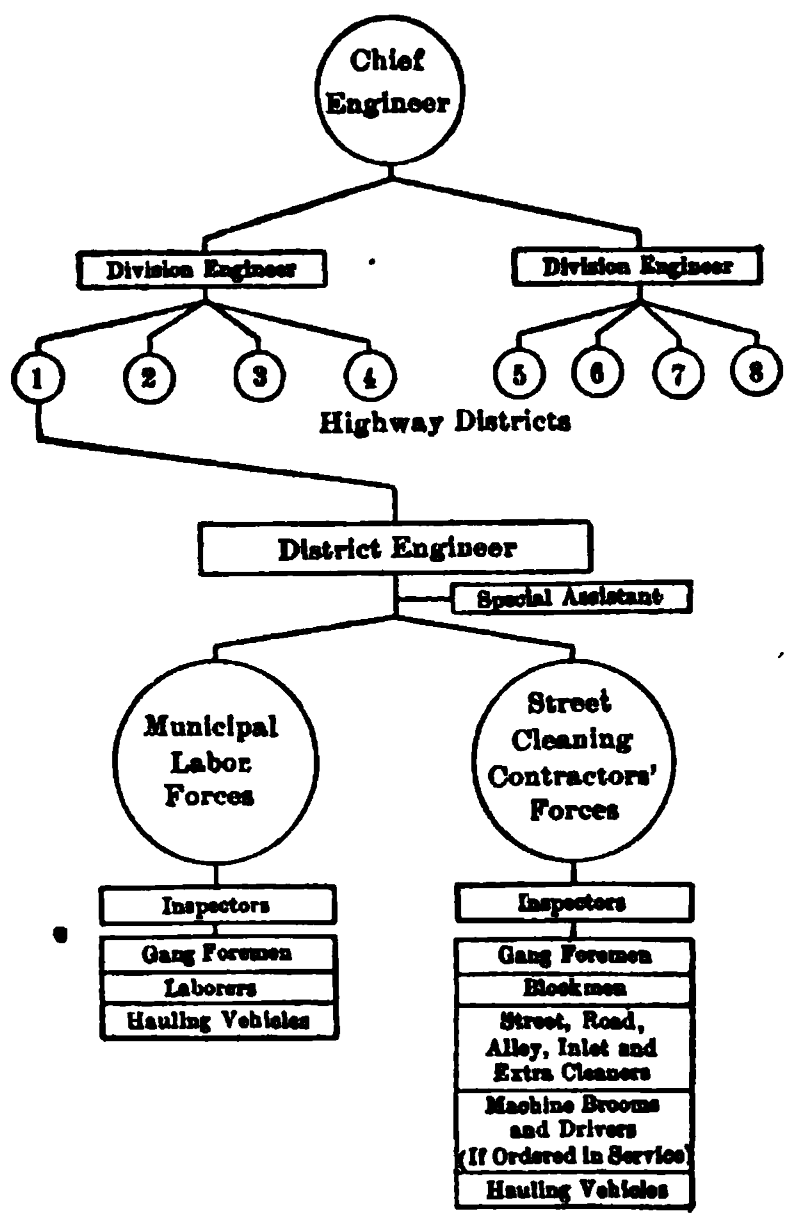

Fig. 6. Organization Chart of the Emergency Snow Removal Work in the Central Business Section of Philadelphia

Details of Operation of Snow Alarm. At any hour of the night, as soon as the snow started to fall the Electrical Bureau in the City Hall notified the Chief Engineer of the Bureau of Highways and the several division and assistant engineers in charge of snow removal work, by telephone in their respective homes. The engineer in general charge of snow removal work lived in the central part of the city and when weather conditions necessitated was in constant communication with the Weather Bureau and the Chief Engineer of the Bureau of Highways. This engineer also kept an hourly record of the thermometer and barometer readings, the depth of snow, direction of wind, so that an exact history of every storm was at hand. The snow alarm or the order to mobilize the forces and begin snow plowing or removal operations was given by the Chief Engineer of the Bureau. This action was based on the likelihood of the depth of the snowfall of 2 in or more, and the existing and predicted weather and temperature conditions. In giving the alarm the Chief Engineer telephoned his instructions to the assistant engineer in charge, who immediately transmitted these instructions

to the several division engineers. The division engineers in turn communicated with their special assistants, who immediately reported at the main office. The issuance of instructions to all concerned occupied but a comparatively short time as the Electrical Bureau handled all calls in connection with a snow alarm as emergency calls.

The inspectors assigned to the snow plows were first called to duty. These inspectors reported at the stables and garages where the respective plows to which they were assigned were kept. Each inspector had the names and addresses of the plow operators and it was his duty to see that the contractor or his representative assigned to the stable or garage made immediate arrangements to get these men to report to the stable. Arrangements were also made with the Police Department to aid the inspectors in reaching the men and upon request patrolmen were assigned to this duty. When the plows were ready to start work the inspectors notified the main office and the plows were kept in readiness until ordered to work. This scheme put the department in control of the plows at the beginning of the storm.

As soon as the indications pointed to a continuance of the storm the entire snow-fighting equipment was ordered out, upward of 1000 telephone messages being sent out to various parts of the city calling out squad leaders, inspectors, drivers, teams, laborers, and officers in the various police districts who aided in getting out the men. This army of laborers and teams kept constantly at work in day and night shifts, plowing, shoveling and dumping the snow into sewer manholes and into the Delaware and Schuylkill Rivers. Every man in the snow removal organization had a particular function assigned to him. For instance, each dump inspector knew just what to do when he got there; the driver of every team knew where he was to report, at what point he was to start to load, and at what sewer manhole or wharf he was to dump his loads, and there was no confusion. Fighting the snow at night during some of the storms during the period of 1912 to 1917 was no easy task for the engineers assigned as squad leaders, the inspectors and the laborers, and it required the constant presence of the Chief of the Bureau and his principal assistants to encourage the men and stir up the necessary enthusiasm to keep the work going.

The main idea in the Philadelphia snow alarm was simply the practical application of the principle of preparedness in the work of snow removal. The organization had been instructed in the methods that under the circumstances would seem to be best adapted to prevent interruption to traffic during and after a snowfall. During the daytime the mobilization of the snow fighting forces was an easy matter as compared with turning out this force at night. It is practically impossible to get a great number of laborers to work at night during a very severe storm, and to offset this great stress was laid on the use of the snow plows to keep the streets open to traffic. Whenever the storm occurred in the daytime or at night when the weather conditions were not too severe considerable of the work was performed by flushing, sweeping and shoveling snow into sewer manholes and inlets. This method could not be depended upon in a heavy storm as it would be practically impossible to get a sufficient labor force to work to keep the streets open to traffic, and it is for this reason that the plows should be kept constantly at work plowing the snow to the side of the street during the progress of the storm. This keeps the streets open to traffic when difficulty is experienced with the labor situation. There never should be very great difficulty in getting laborers and teams in the daytime or at night to load the snow piled at the side of the street into the wagons and haul it to the dumps. It is difficult, however, to secure sufficient laborers to dispose of the snow by shoveling it into sewer manholes. This feature of the work should be simply supplemental to the main feature, which is the use of the plows to keep the streets open to traffic, and after several years' experience with this method it would seem good policy to have on hand snow plows and place the main dependence upon them, as it takes very little time to get them on the work and it is possible to keep them at work at all times, even during the most trying conditions. When the snow is plowed to the side of the street it simplifies loading it in wagons for disposal.

Availability of Employees for Duty. All employees assigned to snow removal work should be on duty at all hours of both the day and night during the entire winter season, subject to call at any hour of the day or night to report for the routine performance required by their respective assignments. When the weather conditions are such that snow may be expected the employees should be required in case of absence from the scheduled call address, to make suitable arrangements for receiving

immediate notice of any order to report for duty that may be sent them and to hold themselves in readiness for a subsequent call. Employees should be required to promptly advise the assistant engineer in charge of snow removal work of any change in their call addresses or telephone numbers.

Arrangements for Calling Snow Removal Forces to Duty. Both the division engineers and the district engineers should be required to maintain a complete roster of both the regular municipal labor and street cleaning forces and the emergency snow removal forces under their respective jurisdiction. This roster should contain the name and call address and telephone number by which each member of the force may be reached, and also the numbers of the police districts in which their homes are located. Each of the municipal gang labor foremen should be made personally responsible for the notification and reporting on the work of a selected number of the municipal labor employees living in his locality. The inspectors and gang foremen should, when weather conditions make it necessary or advisable, hold themselves in readiness to be called, but need not, however, telephone to the office. When an employee cannot be reached by telephone the police district in which his home is located should be requested to notify him by sending a policeman to his home. After proper notice is given the contractors should, however, be responsible for the prompt reporting of their forces on the work in accordance with the pre-arranged assignments.

Duties of Division Engineers. The division engineers should be required to exercise a vigorous supervision over both the emergency and the regular district snow removal work under their respective supervision, and to see that the work is conducted in such a manner as to satisfactorily meet the prevailing conditions. The amount of time spent by the division engineer in either the office or supervision of the work should be governed entirely by the current requirements of the work, but all work of a routine nature should be assigned to their special assistants.

Duties of Special Assistants to Division Engineers. The special assistants to the division engineers should be instructed to report promptly at the main office when the weather conditions seem to indicate that a snowfall of 2 in depth or more will occur, and on arrival at the main office they should immediately report their presence to their respective division engineers either verbally or by telephone. The special assistants should be provided with a copy of the organization schedule and the call addresses of all of the employees and contractors assigned to snow removal work, the planning board equipment, hauling tickets and report forms. When instructed to order out the forces they should transmit the instructions to the several squad leaders assigned to their respective divisions. The special assistants should be required to keep in close touch with the U. S. Weather Bur. in order that there may be a knowledge of any forecasted weather conditions that may influence the manner in which the work may be prosecuted.

Duties of Squad Leaders. After receiving notice to begin operations the squad leaders should be responsible for the prompt reporting on the work of the inspectors and the contractors' equipment and forces assigned to their squad and should see that the snow removal work in the respective districts is promptly begun and performed in an effective and systematic manner and that the assistant engineer in charge is kept advised of the progress of the work by making informal verbal or telephone reports at hourly intervals during the day and by submitting a formal report summarizing the performance for each day. Prior to the advent of snow, however, the squad leaders should be required to fully acquaint themselves with the physical and traffic conditions existing in their respective districts, the location and character of the assigned dumping places, the quantity and character of and the storage locations of the contractors' equipment, and the names and call addresses of both the contractors and inspectors assigned to their respective squads. They should be required to see that their inspectors and the contractors are thoroly instructed in their respective duties to insure that there will exist no possibility of misunderstanding concerning any detail of the work. The squad leaders should also be required to provide themselves with the following forms and data: Specifications, schedule of streets and limits included in each district, snow removal map, organization schedule and call addresses of employees and contractors reporting to them on snow removal work, dumping and loading work tickets and daily report forms.

Duties of Inspectors. The inspectors should be in constant and direct supervision of the work and be required to see that the snow is promptly and properly plowed

into windrows adjacent to the curb and shoveled into suitable piles at such locations as they may designate, and then promptly hauled away. The inspectors should be required to measure and calculate the cubical carrying capacity of all vehicles engaged in hauling and to see that these vehicles are fully and properly loaded and discharged at the assigned dumping places, and to issue work tickets therefor. They should also be required to see that any equipment hired at per hour rates is kept constantly in effective operation.

Traffic Requirements. It should be required that snow removal work be conducted in such a manner as to cause the least possible obstruction or inconvenience to traffic. The inspectors, upon beginning operations, should explain to the nearest traffic policeman just what work is to be done and the proposed manner of doing it, and request his active coöperation toward its efficient performance. The traffic policeman should be authorized to permit the work, if this be necessary to proceed, in a direction opposite to the direction of traffic if this will not cause serious interference.

Maps, Instructions and Record Forms. To assist in the efficient operation of the snow removal work the following instructions and forms should be provided:

Maps, indicating by colors the highways included in each of the central snow removal districts and the nature and exact location of the snow dumps. A properly mounted copy of the map serves as a planning board upon which the progress of the work is shown graphically by the means of glass-headed pins of various colors and sizes.

Planning Board, consisting of a mounted snow removal district map legend and a graphic progress record with glass headed pin indicators of various sizes and colors.

Detailed Instructions, which definitely indicate to the assistant engineers and inspectors supervising the snow removal, the nature of the work to be done and the methods to be used in its performance and their duties in connection therewith.

Organization Schedules, indicating the name and the call address and telephone number, and the assignment of each employee detailed to snow removal supervision.

Hauling Work Tickets of distinctive colors respectively for loading and dumping.

Ticket Issue Records.

Current Status of Work Records.

Squad Leaders' Daily Reports.

Squad Leaders' Daily Report Summary.

Snow Removal District Maps. Snow removal district maps, a copy of which should be issued to each squad leader, contains for each of the several emergency snow removal districts in the central business section of the city, the following data: The highway included in each district, indicated by color; the name of the squad leaders and contractors and the exact locations and characters of the dumping places. The map further indicates the dumps specifically assigned for the use of each of the several district contractors.

Planning Board. In order to provide a better means of directing the emergency snow removal operations in the central business section than would be possible thru the study of records, a planning board system should be installed by which it is possible to visualize with a minimum of effort the current status of the work in each district with respect to character and quantity of force employed and the progress of the work. This equipment should consist of a mounted copy of the snow removal map supplemented by a legend, graphic progress record, Fig. 7, and indicators consisting of glass headed pins of various colors and sizes. The map indicates the area of highway from which snow is to be removed that is included in each district and also the location of the dumps. With the pin indicators it is possible to indicate at which dumps and other locations inspectors are either on duty or needed and if a dump is in service. By hatching and cross hatching the colored portions of the map it is possible to indicate

respectively what relative postion of the streets have been plowed or entirely cleared of snow. By inserting the proper kind of indicators in the proper space on the graphic progress record it is possible to indicate for each district the numerical strength and character of labor and equipment and also to show if these forces are assembled, ordered on duty, or if they are working or have suspended operations. With this equipment, which can be posted in a few seconds, it is possible to determine at a glance, information which, if in the form of written records, would require considerable time and even then could not be visualized.

Detailed Instructions. For the purpose of uniform guidance each member of the engineering and inspection forces assigned to the supervision of snow removal work should be furnished on or before Nov. 1st of each year, with a set of detailed instruc-

Fig. 7

tions outlining their respective duties and indicating the manner in which the work is to be performed. These instructions should remain in force until formally amended or recalled.

Schedules of Proposed Work. On or before Nov. 1st of each year the several division engineers and district engineers should each be required to prepare and submit to the Chief Engineer for approval a complete schedule of the proposed snow removal operations in the territory under his respective jurisdiction during the coming winter, together with an estimate of the probable force and equipment requirements and a statement of the proposed assignments of both the emergency snow removal contractors' forces and the regular street cleaning and municipal labor forces in connection with this work. In this schedule there should be included a definite assignment for each individual assistant engineer, inspector, foreman and gang and a summary of the character, quantity and sequence of the work proposed to be performed. After the approval of these schedules the several division engineers and district engineers should be required to immediately acquaint their subordinates with the exact nature of their respective assignments and duties and to further review this matter with their subordinates whenever it is thought to be necessary.

Work Tickets. The responsibility for the safeguarding and issuance of the loading and dumping tickets, Fig. 8, should be centralized in one person in the main office, who obtains a receipt on the ticket issue record for all tickets issued, and upon the return of the used tickets and ticket packet stubs checks these against the receipts to insure that no tickets are unaccounted for. The inspectors should be required to carefully guard the tickets in their possession so as to prevent loss or unauthorized use, and in no case should the inspectors be permitted to sign these tickets in advance of their actual issuance. All inspectors' signatures should be signed in either indelible pencil or ink, and the date of issuance indicated on all tickets and also the serial number of the ticket for which it is exchanged. The squad leaders and inspectors should be required to see that at all times they are supplied with a sufficient number of tickets

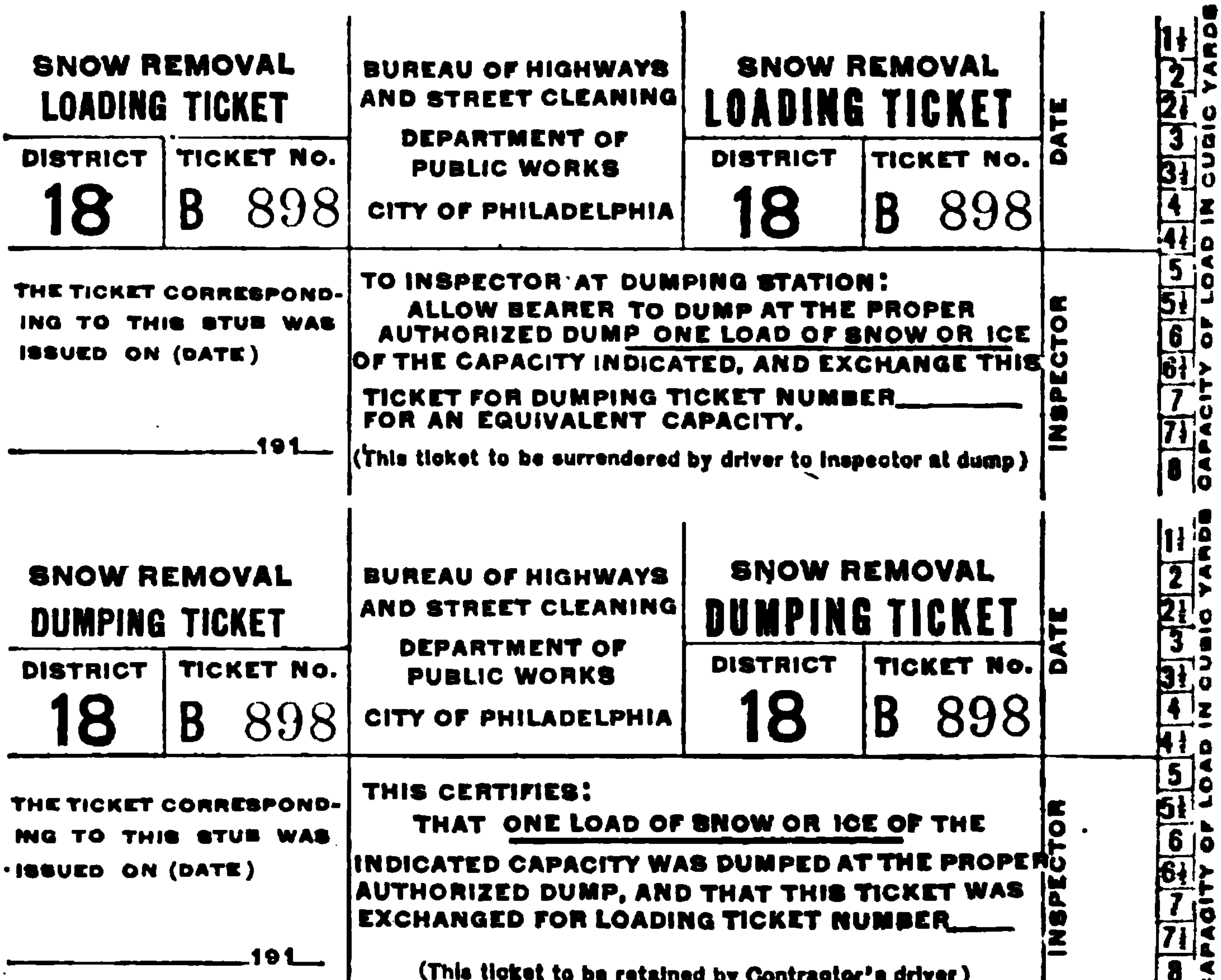

Fig. 8

to meet the requirements of the work. All tickets and stubs should be required to be promptly returned to the office at the termination of the inspectors' period of duty.

Current Status of Work Record. The separate special assistants should be required to maintain for each snow removal district a permanent record of the current status of the work compiled from the informal hourly reports telephoned or made verbally to them by the squad leaders. Upon this report should be recorded from the informal reports made by the squad leaders for each specific district, the date and hour of the report, the force of labor and equipment at work, the progress and condition of the work and the name of the squad leader making the report. The entries on these reports are intended to constitute a complete historical record of the current progress of the work.

Squad Leaders' Daily Reports. The inspectors should be required to submit formal daily reports relating to snow removal work. Any information that an inspector has to report should be communicated to the squad leader to whom he reports. The squad leader should be required, however, to submit to the assistant engineer in charge a daily report. This report should contain a record for a specific district of the time that both the plowing and removal forces were ordered to report for duty, and the

times of their beginning and quitting work, the name and limits of each highway upon which work was done and the character and quantity of work performed, together with the number of both loading and dumping tickets issued, a record of the working quantity hours worked and total force, hours for each class of labor and equipment employed, the names, nature of assignment and working hours of inspectors, the contractor's name, weather and temperature conditions, and any other pertinent information relative to the prosecution of the work that should be of record. The reports should be mailed, or delivered in time to reach the main office on or before the morning of the business day following the date of the report. At the expiration of 1 hr after arriving on the work, squad leaders should be required to report by telephone to the special assistant the general status of the work and to subsequently report thereafter in the case of any important changed conditions or irregularities in the performance of the work.

Summary of Squad Leaders' Daily Reports. Upon the receipt of the several squad leaders' daily reports for work in connection with each separate storm there should be compiled a summary of the reports. This summary should indicate for each district and for the day that the work was in progress, the character and quantity of the forces employed and the number of loads and cubic yards quantities of snow removed. From this data can be determined the total quantity of snow removed and both the actual and contract unit and the total cost of the work.

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SECTION 23

CAR TRACKS AND PIPE SYSTEMS

BY

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CAR TRACKS

1. General Conditions Affecting Car Tracks

Development of Traffic. The problem of constructing street-car tracks in a satisfactory manner in paved streets has been one which municipal engineers in charge of pavement construction have been trying to solve for many years. In the early days of street-railways, when the streets were paved with cobblestones and the cars used were small and drawn by horses at a speed of 5 or 6 miles an hr, this question was not so important; but in the present time of improved pavements, of rubber-tired bicycles and motor-cars, used both for pleasure and for business, and with street-cars weighing from 25 to 35 tons, propelled by electricity along heavy traffic streets at a speed of from 8 to 15 miles an hr, the importance of good and smooth track construction, both to the general public and the street-car companies themselves, can hardly be overestimated.

Factors Influencing Design. It is an undoubted fact that the construction in the street-car area of a pavement different from the pavement itself is a detriment, both because it is difficult to maintain the two constructions at an even surface and because they must be of different degrees of hardness, and consequently the wear from traffic must be uneven. Of all the constructions built into a street, the street-car track is probably more difficult to deal with than any other. If the track were owned and the railroad operated by the municipality the problem would be simpler, but such is not the case in the United States. Altho a street-car track in a paved street is recognized to be an evil, it is also recognized to be a necessary evil, for, as cities develop and grow, it is absolutely necessary that

their inhabitants have means of transportation, not only from place to place in the cities, but from their centers to the outskirts and suburbs where most people live. The question of street-car track construction is different from that of the ordinary railroads. Steam cars generally run on their own right-of-way, making stops only at long and stated intervals, and the tracks can be constructed in such a manner as will give the best results as regards economy of construction and maintenance, with no regard for the wishes of others except at street or road crossings. In paved streets, however, the problem is different, and is one that taxes to the utmost the municipal engineer. He recognizes, however, that the tracks must exist and that he must get the best results with them located in the street. The problem, too, is complicated by the fact that the street-car companies control almost entirely the space occupied by them; that is, under the law, in accordance with their individual franchises, they must construct and keep in repair the pavement within and generally 2 ft outside of the rails. The matter of track construction, too, is different at the present time from what it was 40 or 50, or even 20 years ago, on account of the changes, not only in the pavement, but in the cars themselves. Street-cars run, it must be remembered, not only for the benefit of the corporations owning them, but also for the travelling public, and whatever can be done to facilitate rapid transportation of the public is a benefit to one as well as to the other, altho in a different way. Probably at least 40% of all the business men in the average American city of more than 100 000 inhabitants depend more or less upon the street-cars for their conveyance every day. The street-railway authorities and the officers of the city in which they operate often differ considerably in their ideas as to what is the proper track construction. The street-car companies are interested in performing their work economically, and a construction that will allow their rolling stock to be operated with the least amount of wear and tear, and will cost least for original construction and for maintenance, is what they desire. On the other hand, the officials of the city are not interested either as to first cost or the cost of maintenance, except as to how the repair work on the tracks interferes with the general public.

Use of Tracks by Vehicles. In the early days of street-car track construction, when the pavements outside the track area were rough and uneven, vehicular traffic on the street often took to the street-car tracks in preference to the pavement, and interfered to a great extent with the operation of the cars. The companies sought in every way to prevent this, to such an extent indeed that sometimes it seemed as tho they laid a type of rail that should be an obstruction to traffic. With the old rough stone pavements the actual form of the rail, even if naturally obstructive, did not add very much to the general roughness of the street, but in more recent years, with the advent of smooth pavements, the street-car companies have recognized that their tracks should be constructed in such a way that they will present as little obstruction to street traffic as possible; and, as the pavements are smooth and also kept in better condition, there is not the tendency of vehicular traffic to take to the tracks as existed heretofore.

The Ideal Form of Construction, no matter what its exact type, seems to be one in which the track is practically a part of the pavement construction, and not a separate and definite part of the work. The work each has to do should be studied and considered as a whole. The time of the probable renewal of each should be taken into consideration, and the types so designed as best to accommodate the renewals of each. This

however, is not always practicable, as it often happens that the pavement and the railroad tracks are constructed at different times, when the one last constructed must be adapted as well as possible to the requirements of the former. With the modern and more permanent type of pavement, however, street-car companies recognize the importance of doing their track work, if possible, whenever a new pavement is laid. This is often convenient, from the fact that new types of larger and heavier cars are being introduced, so that new track construction may be necessary. Street-car companies, however, as well as individuals and others, must be governed by financial conditions in carrying out their work, and it generally is a serious proposition for the street-car companies to keep the pavement in their track areas in good condition. It must be acknowledged, however, that the street-car companies thruout the country are recognizing their obligations and meeting them in such a way that conditions in respect to their pavements are improving rapidly, so that in a comparatively few years the pavement in the track areas should be as good as that outside.

2. Franchise Requirements Relative to Car Tracks

Life of, and Payment for, Franchises. The question of the proper payment to be made municipalities for the use of their streets and highways for the operation of street-cars has never been definitely settled. In some cities it is arrived at by the companies paying a certain amount to the city, sometimes based upon the total receipts or the number of passengers carried, or sometimes a lump sum is determined upon in advance. In a new country, where cities are growing rapidly and the matter of transportation is important, property owners are often so anxious to obtain street-car conveniences that they are willing, not only that the company should have a franchise for nothing, but will make certain payments to the company as an inducement for early construction. This for the time being is proper action, as the cars must be operated for a considerable length of time before they will be remunerative from the stockholder's standpoint. On account of this feeling, many franchises have been given for small remuneration that have proved immensely valuable in a comparatively few years. In fact, nearly all of the older street-car franchises in the country were given in perpetuity, and for small sums. In recent years, however, the question of the value of the franchise has been pretty thoroly worked out, and in many cities franchises are given for limited periods only.

American Practice. It can be said, as a general proposition, that the pavement requirements in America of street-railway companies are to lay and maintain the pavement between their tracks and rails and 2 ft outside on each side with such material as is determined upon by the city authorities.

In New York City, for instance, the law provides that no franchise shall be given a corporation, for any purpose, for more than 25 years. In a franchise recently given to the Manhattan Bridge Three-Cent Line, to operate in New York City over the Manhattan Bridge, from approximately the Hudson River in Manhattan to the station of the Long Island Railroad at Atlantic Ave., in Brooklyn, it was provided: "The Company shall pay to the City for the privilege hereby granted the following sums of money: (1) The sum of $15 000 in cash within 3 months after the date on which this contract is signed by the Mayor, and before anything is done in exercise of the privilege hereby granted; (2) during the first term of 5 years an annual sum which shall in no case be less than $4000, and which shall be equal to 3% of its gross annual receipts if such percentage shall exceed the sum of $4000; during the second term of 5 years an annual sum which shall in no case be less than $7000, and which shall be equal to 5% of its gross annual receipts if such percentage shall exceed the sum of

\$7000; the gross annual receipts mentioned above shall be the gross receipts of the Company from all sources within the limits of the City; (3) for the use of the tracks owned by the City upon the Manhattan Bridge and the approaches thereto, the sum of 5 cents for each round trip or the sum of 2½ cents for each single trip of each and every car operated upon the bridge." This is in addition to laying and maintaining the pavement between its tracks and for 2 ft outside on each side.

Dorchester, Mass., Franchise. In 1854 an act was passed by the Massachusetts Legislature incorporating the Dorchester Avenue Railway Co. This was one of the first franchises given for a street-railway. The company was required to keep in repair the whole of the bed of any road in the town of Dorchester in which it might lay tracks. In the following year the act was amended by the repeal of this particular clause and the substitution of a provision that required only that part of the road occupied by the tracks be kept in repair, and defining that portion "to be the space between the rails and so much on each side thereof as shall be within a perpendicular let fall from the extreme width of any car or carriage used thereon, being the space from which public travel is excluded during the passing of said car or carriage."

Baltimore, Buffalo and Brooklyn Requirements. In Baltimore, Md., the street-car companies pave and keep in repair the space between their tracks and 2 ft on each side. In Buffalo, N. Y., different conditions exist in regard to the paving requirements by the different companies, but, in general, the maintenance of the street between the tracks and 2 ft outside is required, the pavement to be of a kind specified by the city. In 1895 a bill was passed by the Legislature of the State of New York providing that one-fourth of the cost of repaving any street in the then City of Brooklyn in which a street-railway was operated should be assessed against the company owning such tracks. Many streets were paved under this law, but no great amount of the tax was collected from the street-car companies. In Brooklyn, N. Y., the original franchises of the different companies generally provided for the repaving of the space between the tracks and rails and 2 ft outside with water stones (known as cobblestones). The companies, however, now generally accept the proposition that they are required to lay a good and substantial modern pavement.

New York State Railroad Law. In 1892 the Legislature of New York passed a law, known as the Railroad Law, a portion of which reads as follows: "Every street-railroad, so long as it shall continue to use any of its tracks in any street, avenue, or public place in any city or village, shall pave and keep in permanent repair that portion of such street, avenue, or public place between its tracks or rails of its tracks, and 2 ft in width outside of its tracks, under the supervision of the proper local authorities, and whenever required by them to do so, and in such manner as they may prescribe. In the case of neglect of any corporation to make these pavements or repairs after the expiration of thirty days' notice to do so, the local authorities may make same at the expense of such corporation." This law has been interpreted to relate to railroads in cities and towns where no special provision was made in the original charters, or where there was any question as to the liability of the railroad to keep the pavement in repair.

Chicago Ordinance. In 1907 the question of the treatment of the street-railway system of Chicago was taken up and a special ordinance passed regulating their construction. The ordinance provided that the tracks should be laid with modern improved rails of the grooved type, weighing not less than 129 lb per yd, and that the rails should be laid upon concrete beams, wooden ties, steel ties, cast-iron chairs, or some other form of first-class modern approved street-railway track construction; the foundation to be of concrete, crushed stone or other ballast material which in the judgment of the Board of Supervising Engineers should best suit the conditions of soil and drainage. As regards the maintenance of the space in the streets occupied by the tracks, it provided that the company should fill, grade, pave, keep in repair, sweep, sprinkle and keep clean and free from snow 8 ft in width of all streets and public ways, or portions thereof, occupied by it with a single-track railway, and 16 ft in width of all streets and public ways, or portions thereof, occupied by it with a double-track railway. It also provided that when the city paved the street in which car tracks were located with an improved pavement, the company should pave its area as given above with a granite block pavement which was described in detail, making a modern granite pavement. It was provided, however, that in any ordinance ordering the paving of streets the company should be required to pave its area with the same material specified for the remainder of the street.

Detroit, Indianapolis and St. Louis Requirements. Detroit, Mich., has what are known as 3 and 5-cent car lines. In streets where the former lines are operated the city paves the entire area, but in streets where the 5-cent lines are operated, the street-car company paves and maintains its area. In Indianapolis, Ind., a readjustment of the terms of the original franchise of the street-railway company was made in 1878, when a provision requiring the road to repave between its tracks was changed so as to read, "repair between its tracks." In St. Louis the companies are required to pave within the tracks and 12 in outside of the rails, with a material that is approved by the city authorities.

Philadelphia Practice. In 1892 the street-railways of Philadelphia changed their power from horses to electricity, and an agreement was entered into between the companies and the city authorities by which the companies agreed to pave and maintain the streets thru which they operated from curb to curb. The streets of Philadelphia are narrow, and in most cases only one track is operated in a roadway, so that a large amount of street mileage is occupied by the street-car companies. More recently, however, an arrangement has been made between the railroad companies and the city by which the former pay to the latter $500 000 annually, and that sum is accepted as fulfilment of the companies paving obligations. From one standpoint this seems a very desirable arrangement, as it obviates entirely any dispute between the city and the companies as to what repairs are necessary, and allows the city to proceed with and make repairs without serving any notice on the companies. If the amount paid is reasonable, it would seem to be the most satisfactory arrangement possible.

In Toronto, Canada, the street-car tracks are owned by the city, but, under an arrangement made in 1891, they are operated by the Toronto Railway Co. In the agreement made between the city and the company it is required that the purchaser shall maintain the ties, stringers, rails, turnouts, curves, etc, in a state of thoro efficiency and to the satisfaction of the City Engineer, and shall remove, renew, or replace same as circumstances may require and as the City Engineer may direct. When a street upon which the tracks are now laid is to be paved in a permanent manner on concrete or other foundation, then the purchaser shall remove the present tracks and super-structure, and repave the same according to the best modern practice, by improved rails, points, and substructure of such description as may be determined upon by the City Engineer as most suitable for the purpose. In the event of the purchaser desiring to make any repairs or alterations to the ties, stringers, rails, turnouts, curves, etc, on paved streets, the purchaser shall repave the portion of the railway so torn up at his own expense. When the purchaser desires, or is required, to change any existing tracks or substructure for the purpose of operating by electricity or other motive power approved by the City Engineer and confirmed by the Council, the city will lay down permanent pavement in conjunction therewith upon the track allowances as herein defined to be occupied by said new tracks and substructures. This at first applied only to existing main lines and thereafter to branch lines or extension to main lines and branches. Under the terms of the agreement the company pays the City Treasurer $1600 per annum per mile of double-track and 8% of the gross receipts, and, when the receipts exceed $1 000 000, 10% is to be paid.

In the City of Washington the amount of pavement to be cared for by the street-railway companies is provided for by an Act of Congress approved June 11, 1878, which requires that: "When any street or avenue thru which a street-railway runs shall be paved, such railway company shall bear all of the expense for that portion of the work lying between the exterior rails of the tracks of such roads and for a distance of 2 ft from the exterior to such track or tracks on each side thereof and of keeping same in repair, but the said railway company, having conformed to the grades established by the Commissioners, may use such cobblestones or Belgian blocks for paving their tracks or the spaces between their tracks as the Commissioners may direct."

European Practice. In Europe, practically the same requirements are made. However, in the larger cities the street-railways are often owned and maintained by the cities themselves; this is especially true in Glasgow and Vienna. In London the London County Council controls and operates both the surface and the underground roads.

British Requirements. General construction of railways in Great Britain is governed by the Tramways Act of 1870. As regards pavements this act provides that

the companies shall repair and maintain the space between the tracks and 18 in on each side. If the work be not properly done, it may, after 7 days' notice, be put in good condition by the road authorities and charged to the companies.

In Amsterdam, Holland, the street-car company is obliged to put the street in good order after construction and to maintain the pavement between the rails and 20 in on each side, and, where the street is not paved, the entire space must be paved by the company. In addition to this the street-car company pays the city the sum of $600 000 annually for general widening of streets, construction and paving of new roads, the building of new and changing and widening of old bridges, the filling and earthing over canals and laying sewer pipes. It may be said that the writer, in an inspection trip thru many of the principal cities of Europe in 1913, found the pavement in the railway area of Amsterdam in a generally bad condition.

The City of Berlin has entered into a very elaborate and specific contract with the street-railway companies. The requirements for laying and maintaining pavements are entered into in great detail, but, in the main, compel the companies to lay a permanent pavement, whenever the remainder of the street is so paved, in the space occupied by the tracks and to a distance of 12 in on both sides of each rail. They are required to keep the pavement between the rails and 26 in outside in good condition.

In Hamburg, Germany, a contract made between the city and the largest of the railway companies requires the company, for a period of 25 years beginning in 1894, to pay the city in lieu of any paving or street cleaning a charge of 1 pfennig (¼ cent) per passenger carried for a cash fare, and 5% on commutation tickets.

3. Location of Car Tracks

After it has once been determined to construct a street-car track in any street the next thing to be determined upon is its location. Ordinarily it is the custom to locate all tracks in the center of the street. As a general proposition this practice is undoubtedly correct, but conditions often arise where it is better to vary the location, and sometimes when the tracks are laid in the center of the street they are separated entirely from the roadway.

Tracks in Sidewalk Space.

In Rochester, N. Y., on streets in the suburbs where the roadways are narrow and the sidewalk space wide, the tracks are sometimes laid in the sidewalk space between the curb and the walk, thus leaving the roadway entirely free. This of course makes it necessary, when using vehicles, for all residents on the street to cross the track in going from their property to the roadway.

Tracks at the Side of Roadway. In some cities the tracks are located in the roadway, but next to the curb. This practice leaves the center of the roadway entirely clear, but it prevents vehicles from being left standing at the curb and makes it awkward to drive up to the curb for the purpose of receiving or discharging passengers, so that the practice as a general rule is not satisfactory.

Paris. A location corresponding somewhat to this was observed in 1913 in a street running out of the City of Paris. Here, the entire street was about 100 ft wide, with the central roadway, perhaps 40 ft wide, paved with stone; in a space about 15 ft wide between the pavement curb and the secondary curb were located the street-car tracks, one on each side; the space between the secondary curb and the building line was treated in the usual way with sidewalk, etc. This, of course, left the entire roadway space free and uninterrupted for travel. The street was a semi-residential, retail-business street, where there would probably not be much passing from the stores to the street, and, in fact, there does not seem to be as much of this in Paris as in American cities.

Central Park West, Borough of Manhattan, New York City. Sometimes, however, where a street runs alongside a park for any considerable distance, the tracks are located on the side of the roadway next to the park, the nearest rail being about 3 ft from the curb. A notable case of this kind is Central Park West, which is 100 ft wide, and runs along the west side of Central Park. The roadway is 48 ft wide, the sidewalk on the east side being 27 ft and on the west side 25 ft. The east track is located with the

rail 3 ft from the east curb, the idea being to get as wide a roadway as possible for traffic. This was very satisfactory when all the vehicles were horse-drawn, but with the increase of general traffic and the speed of the automobiles many accidents have occurred because the northerly vehicular traffic is adjacent to the southerly street-car traffic, so that all people getting off the cars going south are met by the vehicular traffic coming north. Since 1915 proceedings have been under way with a view of changing the location of the tracks from the side to the center of the street, and in order to make this as inexpensive as possible it was proposed to change the location of the east track only, placing it to the west of the present west track, and to set back the curb in front of the park 7 ft. The result of this would be a total roadway of 55 ft, divided approximately into 25 ft for the roadway west of the tracks, a space of 15 ft for the street-car tracks, and 15 ft for the roadway east of the tracks. This arrangement would provide for two lines on the east side going north and three lines on the west side going south. This would relieve the tendency of traffic to crowd up to the street-car tracks in keeping to the right, as it necessarily must do under the present arrangements. This plan has been ordered carried out by the Board of Estimate and Apportionment of the City of New York, but on account of the question of how the cost of same shall be divided between the city and the company the work has not been carried out (1918).

Prospect Park West, Brooklyn, N. Y. Another location similar to this is Prospect Park West, where the tracks are located in the same way, but as the traffic on this street is not great, it not being a thorofare as is Central Park West, no trouble on account of accidents has arisen.

Tracks in the Center of Roadway. The central location, separated from traffic by curbs, is particularly desirable to the street-car companies, especially where the blocks are long, as it not only allows the cars to run more rapidly but they are less liable to be interfered with by vehicles or pedestrians.

In Coney Island Ave., Brooklyn, N. Y., the car tracks were originally located on the west side of the roadway next to the curb. This was on account of some old property rights that the railroad company had in the street. This avenue is 100 ft wide, and had been graded and curbed for a roadway of 50 ft, leaving a sidewalk space of 25 ft on each side. When it was desired to pave the street it was seen that the location of the tracks was not satisfactory, and it was much opposed by the people owning property on the side where the track was laid next to the curb. After considerable agitation and the passage of a bill by the New York State Legislature authorizing the same, the tracks were changed to the center of the avenue, and a space 24 ft wide was given to the railroad company, separated from the traffic roadway by cement curbs, and the old curbs set back 10 ft on each side. There was much discussion by the property owners as to whether this central space should be reserved for the railroad or left in the usual way for traffic. This arrangement gave two sidewalks of 15 ft each, two roadways of 23 ft each, and a railroad area in the center of 24 ft. The blocks on this avenue are some 700 or 800 ft long, but openings were left in this central space, and paved with granite, so that traffic could cross at distances of about 400 ft.

Upper Broadway, Borough of Manhattan, New York City, is wide and has parks in the center; it also has two lines of street-car tracks. These, however, are located adjacent to these central park spaces, and this is probably the best location that could be obtained, as it gives the greatest possible width for traffic, and the traffic, naturally veering to the right as it moves, keeps from rather than towards the tracks.

Beacon St., Boston, is a good example of the location of street-car tracks in the center of the street, where the tracks are separated from the vehicular traffic and the central area is sodded.

New Orleans. The most extensive example of central location where traffic is separated from the street-car tracks is undoubtedly seen in the City of New Orleans, where nearly all of the streets are so treated. Canal St., for instance, which is a business street, 120 ft 6 in wide, is treated in this way. The central portion of the street, where the tracks are located, called there the neutral strip, is 60 ft wide. In other and residential streets, and even where only one track is located, this same method is used. In a climate like that of New Orleans, where the air is moist and

where it seems possible, and even easy, to keep this neutral strip sodded and well grassed, this is a very satisfactory treatment for residential streets, but it would not seem satisfactory for business streets, as then it is desirable to have free and uninterrupted traffic from one side to the other.

4. Rails

Loads Carried by Rails. When the actual work of construction is taken up, the first and possibly the most important thing to be considered is the type of rail to be used, and in studying this question it must be understood that it is a very different proposition from what it was in the early life of street-car companies, as the cars were then light and drawn by horses, while now they are heavy and propelled by electricity. Interurban cars are generally very heavy, some coming into the City of Pittsburgh weighing 35 tons, and others as high even as 50 tons. The new cars used by the Brooklyn Rapid Transit Co., in Brooklyn, weigh 25 tons unloaded, and if it is assumed that they will carry at times 100 passengers, averaging 150 lb each, that will make an added weight of 7½ tons, or a total weight of 32½ tons, when loaded, carried on eight wheels. It can easily be seen, therefore, that track construction for such cars must not only be properly designed, but also properly carried out, and in this the design of the rail plays an important part.

Development of Rail Types. Many changes have taken place since tracks were first laid. The first track laid was undoubtedly very crude, practically a piece of flat iron spiked to a wooden stringer, with a groove in which the flange of the wheel ran, but as traffic increased it was recognized that a more substantial rail was required, and that shown in Fig. 1 was adopted. This was spiked to a stringer, which itself rested on cross-ties, the lip on the left-hand side coming down over the edge of the stringer. The spikes and the rails, however, soon became loosened, and the joint rough and uneven, but with the small cars in use at that time, and the low rate of speed, the discomfort of the passengers was not as great as might have been expected. Fig. 2 represents a rail of the same type, but used on a curve in order to prevent the cars from becoming derailed. The practically square edge of Fig. 1 made it difficult for teams to cross, especially when the pavement was fairly good, so that eventually it became modified to the type shown in Fig. 3. This allowed trucks to pass over the rails readily, but was no better for the passengers or the cars themselves. Fig. 4 shows a modification of Fig. 1, making an actual groove for the flange of the wheel, but without modification shown in Fig. 3, allowing for the easy passage of trucks. If a block pavement had come up against the back of the rail this would not have been necessary, but in the early days pavements were not often so laid. Fig. 5 shows what was generally known as the center-bearing rail. This was practically Fig. 4 doubled. It was claimed by many that the main object of this rail was to make it as obnoxious as possible to vehicular traffic, and anyone who has seen this construction in paved streets knows how successfully it would have accomplished this purpose. The companies claimed, however, that naturally


Fig. 1

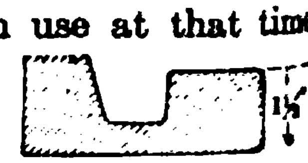


Fig. 2


Fig. 3


Fig. 4

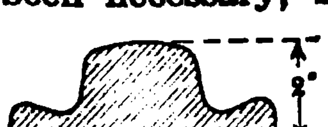


Fig. 5

the wear would be on the inner side of the rail, and that after that was worn the rail could be reversed and the wear taken on the other side. This type of rail was laid in duplicate, with both rails on one stringer, on 14th St., New York City, just west of Broadway.

Removable Heads and Reversible Rails. At one time it was thought that, as the head of the rail was the only portion that received any wear, it might be possible to so design a rail that the head could be replaced, leaving the lower portion intact. In order to accomplish this the rails were made in two parts, as shown in Fig. 6. Fig. 7 shows a type of rail designed to accomplish the same purpose, but of an entirely different type. It must be remembered that if a proposition of this kind were practicable, and a rail could be renewed without disturbing the ties or the base of the rail even, much economy would be effected. This type of rail was used to quite an extent in the street-car system of Brooklyn in 1895. However, the development of street-car transportation made it necessary to change the power from horses to electricity, and also to increase the size and weight of the cars, and it was found that it was not practicable to use rails of this type, as the support was not sufficiently rigid. Fig. 8 shows a center-bearing rail of a design that could be reversed after one side had been worn by the wheels. This style of rail would be extremely objectionable to traffic from both the inside and the outside of the rail, and it was never used to any great extent.

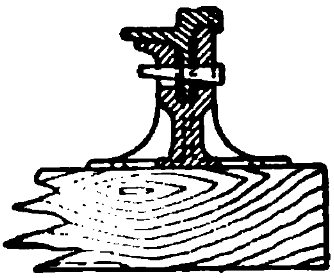


Fig. 6

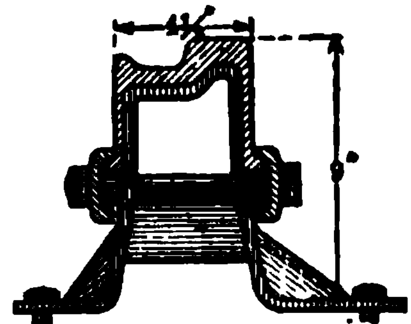


Fig. 7

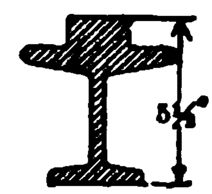


Fig. 8

Side-Bearing Rails. Fig. 9 shows what is known as the side-bearing rail, and was undoubtedly the first form used of this kind; it has not come into very general use. It is particularly attractive to vehicular traffic, especially when the pavement of the roadway is bad, as it generally was when these rails were first adopted, but, on account of its shape, it is difficult for a truck to turn out readily. Also, on account of its wide tram, it is difficult to pave up to it with any kind of a block pavement, as any little settlement at the end of the block will bring it below the tram of the rail, when abnormal wear will occur and a rut soon form. This often took place, as at the time this rail came into use concrete foundations for pavements were very rare.

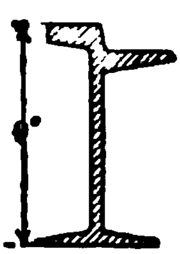


Fig. 9

Grooved Side-Bearing Rails. Fig. 10 shows a grooved side-bearing rail which for many years was the standard rail of New York City. It is known as the Trilby rail. The lip of this type extends to a considerable distance beyond the groove, also forming a convenient wheel track for any vehicle the tires of which are so wide that they will bear on the rim rather than settle in the groove. This has the same objection as that referred to in Fig. 9, of being difficult to pave up against, on account of the long distance between the edge of the lip and the gauge line. This type is objectionable also for the very reason that it invites traffic. The typical rail is one that should neither invite nor repel traffic, but allow it to pass crosswise or diagonally without any interference. Fig. 11 shows practically the same rail, but modified, first, as to the groove,

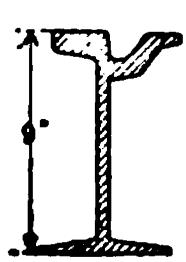


Fig. 10

which is designed so as to be as nearly self-cleaning as possible, and, second, by changing the lip, making it narrower and so reducing the space between the edge of the pavement and the rail, and the lip is at practically the same elevation as the head, so that traffic can pass freely in any direction. These center-bearing rails were designed when granite blocks having a depth of 7 or 8 in were laid. It is not an economical type, as, on account of its height, the web requires more metal than would otherwise be necessary. When granite blocks were reduced to a depth of 5 in, the type of rail was changed to that shown in Fig. 12, weighing 105 lb per yd, which has all the good features of the other rails and gives as good service to the companies, with less metal. This type was used by the Manhattan Bridge Three-Cent Line, previously referred to.

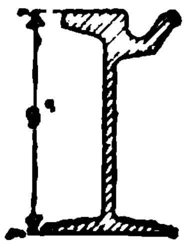


Fig. 11

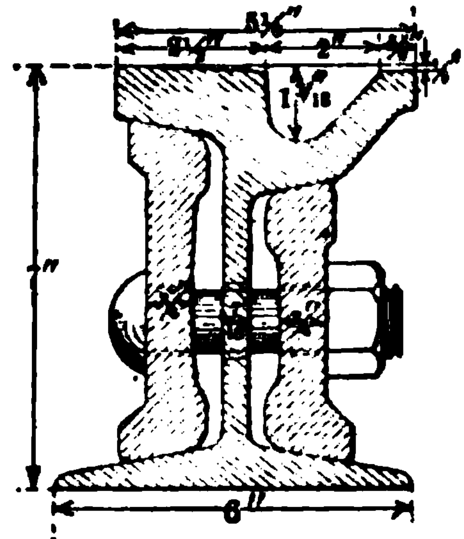


Fig. 12

Life of Rails. It is often asked, as in all other construction, how long will rails last in a street-car track. This question is as indefinite as most questions of like character, as the life of the rail depends so much upon conditions, namely, the weight of the car to be used, the speed at which it is to be operated, the size and cross-section of the rail itself, the foundation upon which the structure is placed, the method of construction, whether the rails are on tangents or curves, and whether there is much starting or stopping on the line. All these matters have a very important bearing on the question, as can easily be understood, and without knowing these conditions it is impossible to form any estimate whatever as to the life of the rail. Some engineers, working by the rule of thumb method, have estimated that a rail will last for the passage of 6 000 000 cars. The above discussion shows how general an estimate this must be. In the Borough of Brooklyn, New York City, on Fulton St, below the Borough Hall, rails were renewed in 1899 that were laid in 1895. This would mean the passage of a little over 2 500 000 cars over the track before it was renewed. It has been stated that the passage of the same number of cars over the Third Ave. Railroad tracks in New York City appreciably wore and hollowed out the rails. This was a cable road. At the present time in Brooklyn it is estimated that the present construction on Fulton St, which has the heaviest traffic, will last for 12 years, while some track is in existence which has been down 18 years and is still in good condition. An extreme case of wear of rails is undoubtedly shown in the operation of the New York subway. On the City Hall loop, rails wore to such an extent that some of them had to be renewed in 5 months; others had a life of from 7 to 8 months. This was on a curve with a radius of 147 ft. At the Grand Central Station, rails were removed after having been in use 12 months and 5 days. These of course are extreme cases, but indicate very plainly the necessity of having all conditions known before any opinion can be formed as to the length of time any track will be used.

5. Construction of Car Tracks

Joints. When the work of actual construction proceeds after the type of rail has been determined upon, one of the most important things to be considered is the joint making. It is recognized by all engineers that the

joint is necessarily the weakest part of the rail unless reinforced with great care. From the pavement standpoint, too, the joint question is important, as, especially when a sheet-asphalt pavement is laid up against the rail, the wear next to the track almost invariably begins at the joints. This causes the rails to work loose, and, with the motion under traffic, allows water to get below the pavement, softening it and causing undue wear. Joint trouble has been eliminated to a great extent by the construction of longer rails. The old practice was to lay rails 30 ft in length, but within recent times rails have been laid 60 ft in length, thus reducing the joints one-half. Many experiments have been made in joint making and many devices used for that purpose. This is important from a railroad traction standpoint, as is shown by a paper by Bowen (14). He stated that when the question of renewing the State St. track, in Chicago came up, a car weighing over 4 tons was run over it, attached to a grip car by means of a dynamometer. The same car was run over a track newly laid and at the same speed as over the old line. The dynamometer showed that it took 13.75 lb more pull per ton to haul the car over the old line than over the new. That he attributed a great deal of this extra power required to the condition of the track at the joints can be seen from his conclusion that a new track with cast joints would last 12 years, and as there will be no low joints, the draw-bar pull will not increase much until the rail is worn down sufficiently to allow the wheel to run on the flange. When it is remembered that some engineers figure that the force required to haul a ton on a well-constructed track should not exceed 8 lb, the effect of the track being in bad condition can be plainly understood. This is especially important as the weight of the car and the speed at which it is run increases. The original method of making joints was by fastening the rails together with steel plates and bolts, but in order to make rigid joints they have been formed by welding with what is known as the cast-welding process. More recently the practice of welding rails electrically has been in use. As the rails are used for the return current of electricity it is important that the connections should be as nearly perfect as possible. Fig. 13 shows, both in section and elevation, a riveted joint. Fig. 14 shows a continuous joint, and Fig. 15 a cast-welded joint, all as used by the Brooklyn Rapid Transit Co.

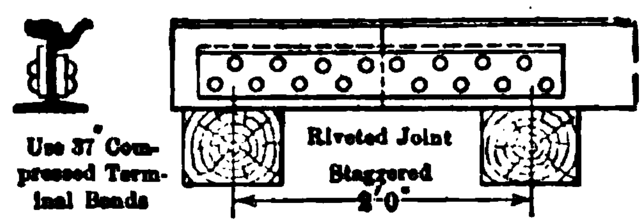


Fig. 13

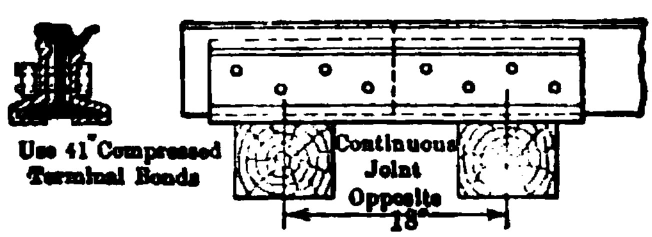


Fig. 14

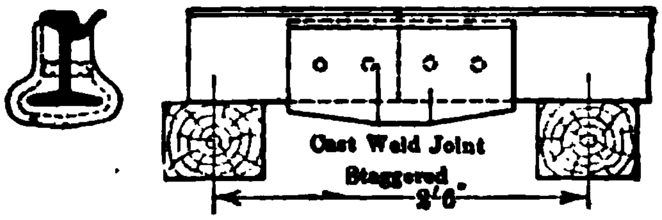


Fig. 15

Ties. It is generally considered good practice, where wooden ties are used, to have them creosoted before being laid, as, with a permanent track construction, if the ties need not be disturbed when the rails are laid, the cost of relaying the track is much reduced. Some companies use steel ties, as will be shown in the different types of paving construction listed, but many like the wood bearing because it gives more resiliency to the rail.

Third Ave. Railway Co., New York City. Fig. 16 shows the form of construction that was adopted when the company substituted electric construction for cables,

about 1899. It will be noticed that the rail is the regular Trilby rail, set on a wooden creosoted stringer. The object of the stringer is to get a certain amount of resiliency in the track so as to make it more comfortable for passengers and easier on the cars themselves. Yokes were placed 5 ft apart from center to center. This construction was used on the subsidiary lines, but on Third Ave. proper the form of the yoke was somewhat changed, and instead of the creosoted beam a heavy spring was used, resting upon the yoke and upon which the rail rested. This spring is so designed that, when the center is depressed, the ends rise, presenting a corrugated surface of such strength that it is assumed it will sustain a weight of 10 000 to 12 000 lb. The springs are 4 in wide, and the deflection at the passage of a loaded car carrying about 6 400 lb on each wheel is about 1/32 in and is noticeable from the street. At the time these tracks were laid the pavement outside of the tracks was granite block, but, as will be seen from the construction of the yoke, it would be extremely difficult to lay a satisfactory granite-block pavement between the rails and the center slot, so concrete was laid to within 2 in of the top of the rail, when about 1 in of asphalt wearing material was spread over the concrete, in which was imbedded a specially designed grillwork of $^3/_4$-in cast-iron bars, forming squares about $3\frac{1}{2}$ in in size. More asphalt was then filled in on top of that first laid, between and around the iron bars, and thoroly rolled and compacted so that the finished surface was in a straight line between the slot and the head of the rail. This form of pavement did not prove to be very satisfactory.

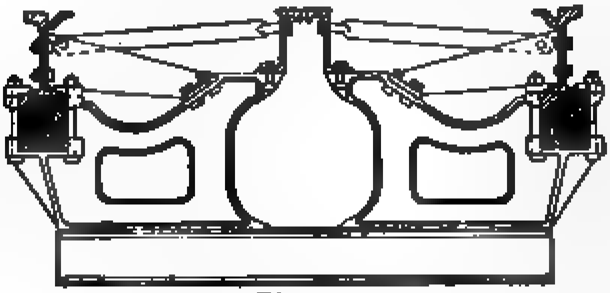


Fig. 16

New York Railways Co. work in the Borough of Manhattan, New York City, in 1915, is shown in cross-section in Fig. 17. It will be noticed that the construction is practically the same as that of the Third Ave. Line, except that the rail rests directly on the yoke and not on the wooden stringer. The yokes are placed 5 ft apart and serve as bearings for the rails.

Coney Island Ave., Brooklyn, N. Y. In the construction on Coney Island Ave., the roadbed was excavated to a sufficient depth, and then broken stone spread over the surface and rolled to a depth of 6 in. Upon this bed of broken stone creosoted ties were placed and T-rails laid upon them. The rails were fastened to the ties with a screw spike pneumatically driven. A T-rail was permitted to be used as the track was nearly all laid in a space separated from traffic, while at the intersections vehicular traffic would be nearly at right angles to the track. This method has been entirely satisfactory.

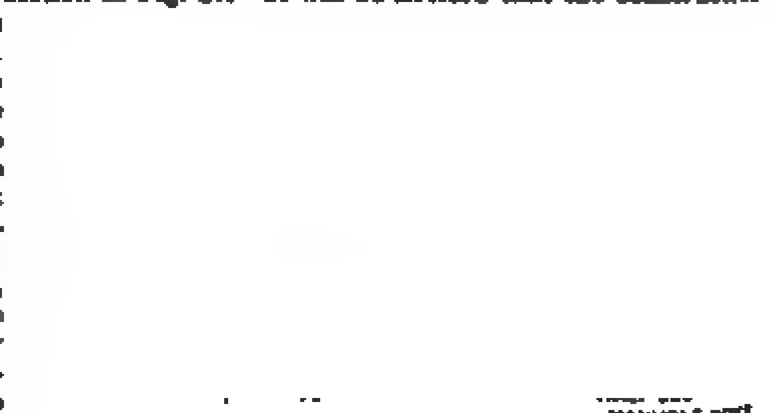


Fig. 17

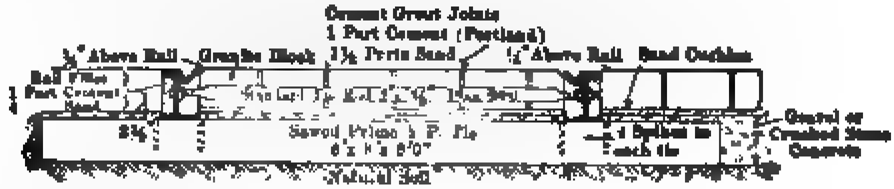


Fig. 18

Brooklyn Rapid Transit Co. Fig. 18 shows the type of track construction in Brooklyn as adopted by the Brooklyn Rapid Transit Co. It will be noticed that the ties are laid upon the natural soil. In this connection it should be said that the soil of Brooklyn is sandy and artificial drainage is not necessary. This company has laid a good many miles of track of this character, with extremely satisfactory results. As a general proposition, however, it would seem that some kind of artificial foundation was necessary, but this must be determined by conditions. Fig. 19 shows a type of construction with steel ties of the Brooklyn Rapid Transit Co. A track laid in this way was constructed on Flatbush Ave., leading out towards Prospect Park, and has proved exceedingly satisfactory. Vehicular traffic can pass over it freely from one side to the other, either diagonally or directly across, without any interference whatever. It is exceedingly pleasing also to ride over, as the rails along the foundation are solid and the track surface correspondingly smooth.

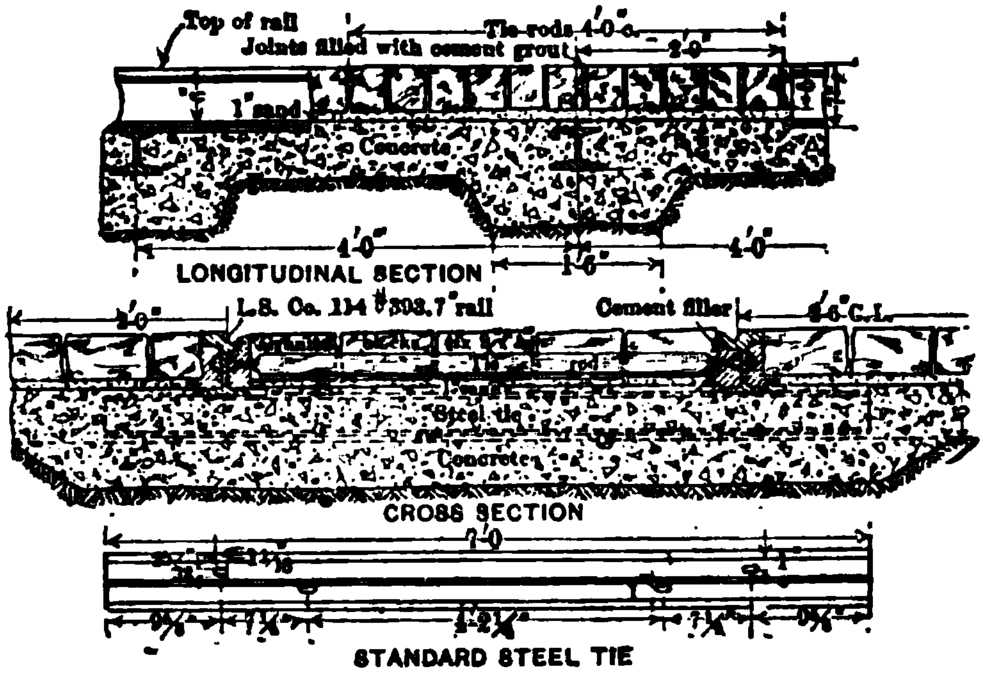


Fig. 19

Cleveland, Ohio. Fig. 20 shows a somewhat similar construction used in Cleveland. The joint fastening should be noted, as the plates extend the full depth of the web.

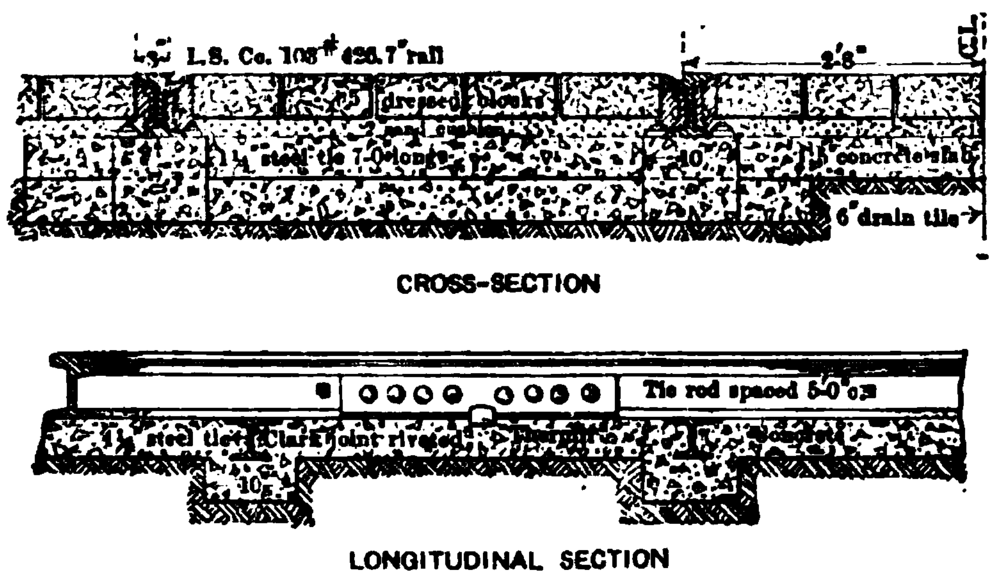


Fig. 20

Rochester, N. Y. Fig. 21 represents a cross-section of a portion of a car track in Rochester as used in 1900. It shows plainly the concrete beam under the rail and the steel tie which was used at that time. Fig. 22 shows another portion of the same construction. The

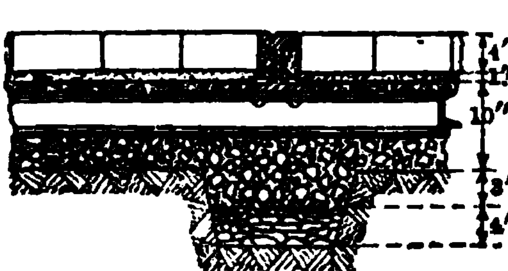


Fig. 21

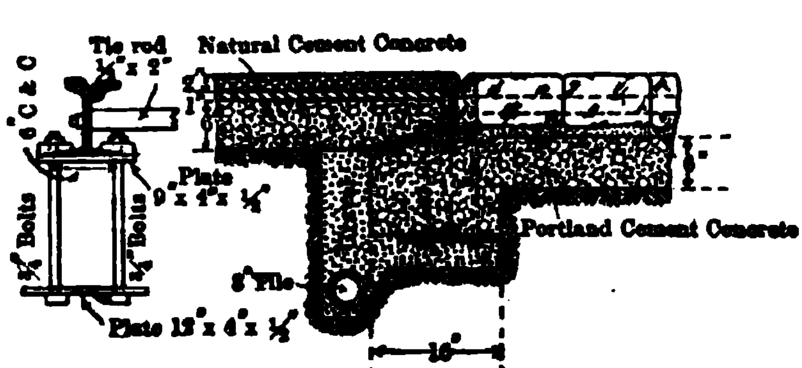


Fig. 22

rails were clamped to the concrete beam, as shown, there being three clamps to a 30-ft rail and five to one 60 ft in length. A cushion of asphalt mastic ½ in thick was laid

on top of the concrete beam, making the same more resilient. Attention is called to the provision for drainage should any water seep thru the joints of the blocks down to the sand cushion. The soil of Rochester is clayey, so that provision for drainage is necessary. Fig. 23 shows a cross-section of street-car track construction in Rochester in 1915. The Consulting Engineer of that city writes, as follows: "We are satisfied, from our experience, that a broken stone foundation is better for heavy traffic, especially where it is difficult to keep the street closed for a sufficient length of time to let the concrete become properly set. We have tried every kind of construction in railway tracks and are satisfied that the T-rail with a special Medina or granite block, cut as shown on the print, makes as good a track as any other construction, and very much better than any of the other half-grooved rails that have been used heretofore. We have abandoned the use of the steel tie and are using wooden ties entirely at the present time. These ties are spaced 2 ft apart."

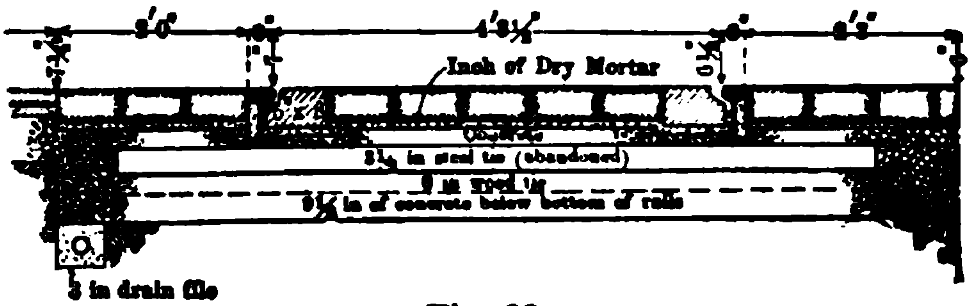


Fig. 23

Detroit. Fig. 24 shows the standard track construction in Detroit in 1912, a T-rail being used. It will be noticed that the ties are bedded in concrete and that the joints are cast-welded. Fig. 25 shows a grooved rail construction in the same city in 1913.

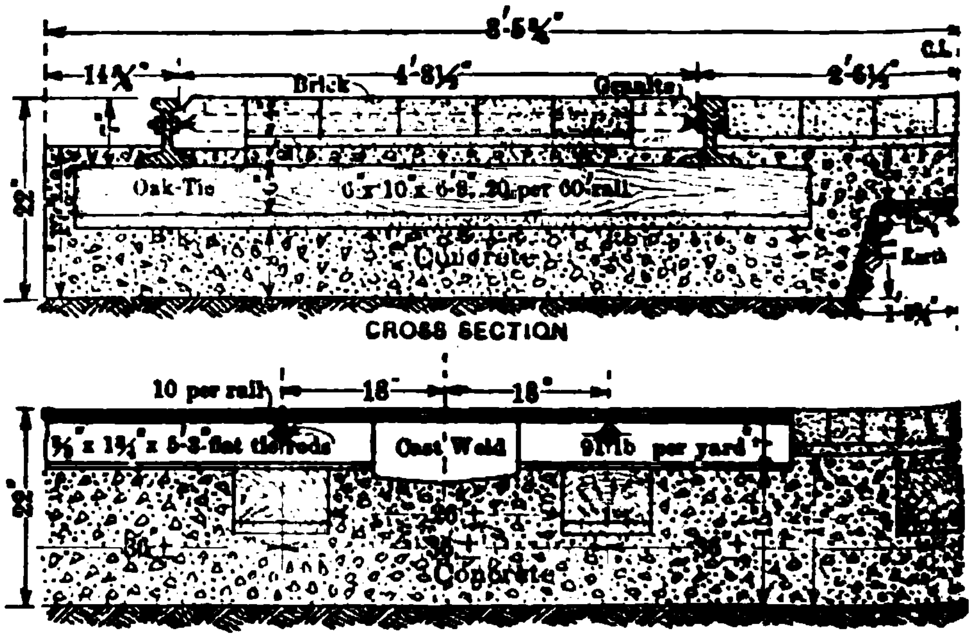


Fig. 24

Kansas City, Mo. Fig. 26 shows construction in Kansas City as of 1912. Attention is particularly called to the type of rail and the result obtained when a block pavement is laid up against it. It is extremely objectionable, as was undoubtedly ascertained by the company, as Fig. 27 shows standard construction in the same city as of 1913, the rail being of the T type.

Newark, N. J. Fig. 28 shows standard construction in Newark in 1912, and Fig. 29 construction in the same city for 1913. The construction is practically the same, altho the pavement is of a different character.

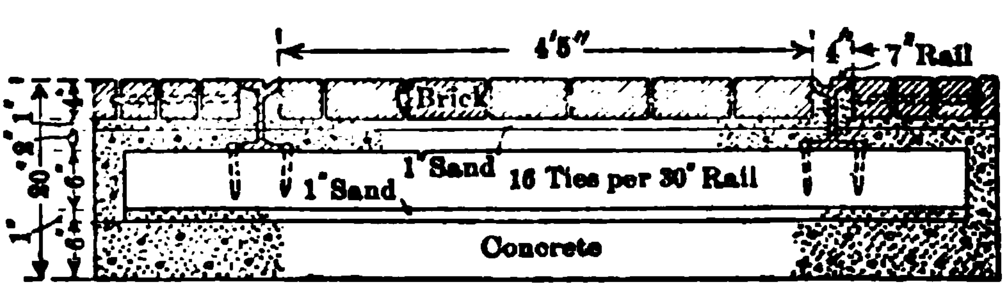


Fig. 25

Philadelphia. Fig. 30 shows track construction in Philadelphia. This, as will be seen, varies materially from construction in other cities, the rails being placed on chairs embedded in the concrete. Attention is called to the way the outside edge of the rail is bevelled off and how unnecessary this is when a square block is laid against the rail. In 1915 it was stated that the concrete construction had practically been abandoned and the ties laid on the natural ground.

Boston. Fig. 31 shows Boston construction in 1912, the grooved rail being set upon

ties in much the same way as was shown in Cleveland and Brooklyn. Fig. 32 shows construction in Boston in 1915. The Engineer of the road states, in connection with this, that the tendency now is to do away with concrete in foundation for tracks, on account of its being too rigid, and broken stone is generally used in its place.

The Board of Supervising Engineers of Chicago adopted the different types of construction shown in Figs. 33 and 34, the method varying according to the rail and foundation.

Fig. 26

Toronto, Canada. Fig. 35 shows track construction as used in 1915 in Toronto. The Commissioner of Works of that city states: "During 1913 and 1914 the concrete substructure of all new track allowances in the city were 15 in in depth, being placed in two courses, the first course of 9 in being brought up level with the bottom of the tie, and the second course of 6 in being placed later. This practice is carried out in order that a firm basis may be provided for the tie and provision made for shrinkage in the concrete. We introduced, last year, wooden filler strips to take the place of the mortar casing which was formerly used, and which was always a source of trouble, and, from indications to date, we are led to believe that this form of construction will be much more satisfactory than the former."

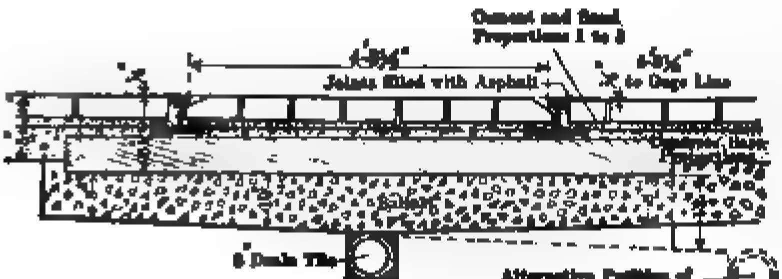


Fig. 27

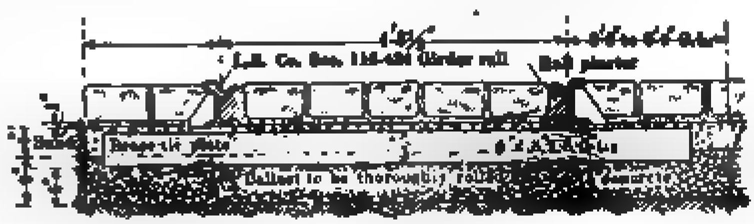


Fig. 28

Filling for Rails. It is important, especially where the pavement is made of blocks of any kind, that the space between the web and the lip of the rail be filled substantially with some solid material, as,

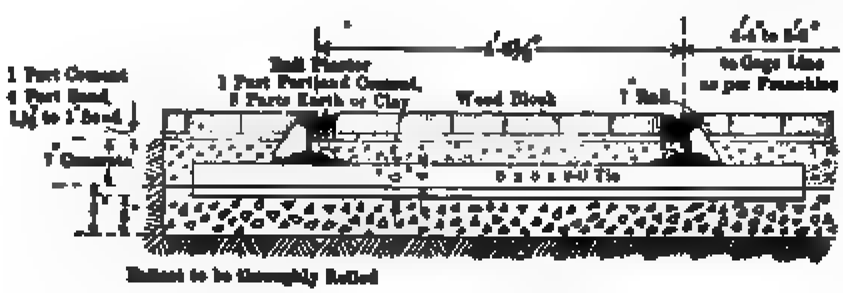


Fig 29

if it is not so filled, the blocks are liable to settle under traffic and permit a rut to be formed adjacent to the rail. Three materials are used for this purpose: Cement mortar, burned clay blocks, and wood. The cement

mortar mixed in the proportion of one part of cement to two or three parts of sand is most generally used, and is probably the best. It can be easily applied and, after it has set it is strong and solid. Burned clay brick does not fill the space exactly, and, in any event, has to be burned specially for the rail. The wood is undesirable for the same reason, and, unless creosoted, is liable to decay long before the pavement or the rail itself is worn out and thus lose the efficiency it had in the beginning.

Fig. 30

B.R. Sec. # 4 (Penn. Sec. # 279)

Fig. 31

Pavement Next to Rails. In the laying of pavement in a street-car street it is claimed by many that sheet-asphalt should not be laid

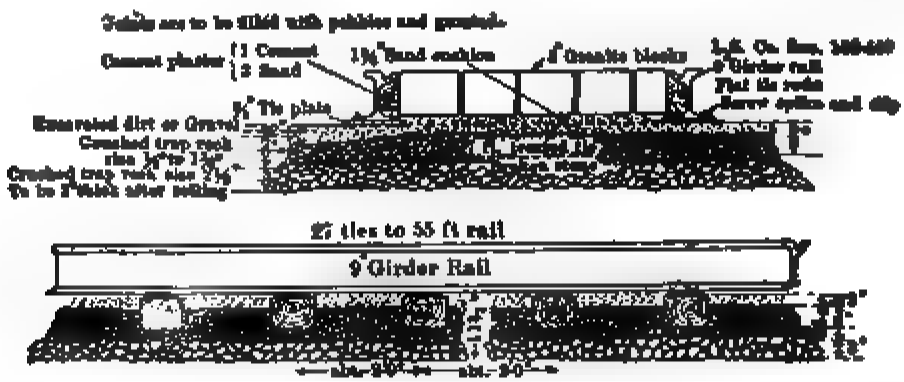
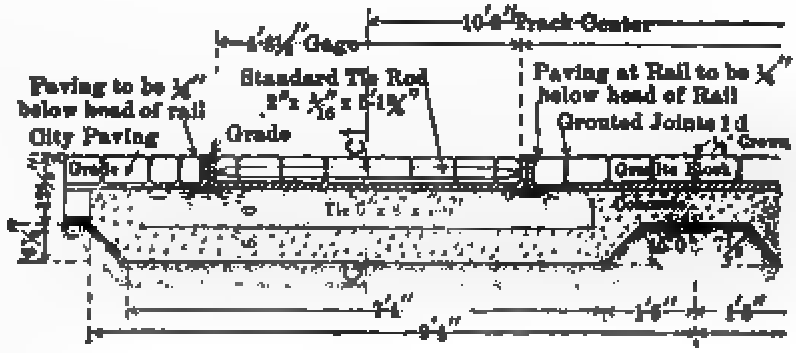


Fig. 32

directly against the rails, as the wear will be such that it will be neither economical nor desirable. The alternative is for the street-car company to lay outside of the rail a block pavement of some kind: stone, wood or brick. While this practice has proved satisfactory in many cities, it has one objection, that is, it forms a longitudinal joint between a hard and a comparatively soft material, which is in the

Fig. 33

line of traffic, and for that reason liable to form a rut under heavy traffic. In Brooklyn, N. Y., the practice has always been to lay the sheet-asphalt directly against the rail, and very many miles of this construction are now in use. While with bad track construction it is undoubtedly true that more than ordinary wear will take place next the rail, yet with such tracks as should be laid in modern times, with the present weight of cars, it seems that the sheet-asphalt can be satisfactorily laid up to the rail itself



Conclusions, Spec. Com. Mat. Road Cons., Am. Soc. C. E. (10). "Uniformity in the roadway surface being essential for minimum wear and expense of maintenance, anything, such as manhole covers or street-car tracks, introducing an element of non-uniformity into the surface, should be counteracted as far as possible whenever surfaces of different degrees of hardness adjoin in a pavement. The traffic coming from the harder to the softer surface naturally causes abnormal wear on the latter. In the case of car tracks in streets, modern construction is such that the tracks are nearly rigid, altho this condition does not exist in all cities at present. Where it does exist, however, the pavement should be laid somewhat above the level of the rail. The Committee, however, does not believe that in any case a bituminous pavement should be laid between the tracks or between the rails of the tracks. When car tracks are laid in roads, the construction is not generally as nearly rigid as in streets, and the rails are usually of the T form. The tracks in such cases are often laid at the side of the road, rather than in the center, as is customary in streets. In the case of macadam or bituminous roadways, and when the rails are in the center, it would be advisable to lay stone blocks or brick for a width of at least 18 in

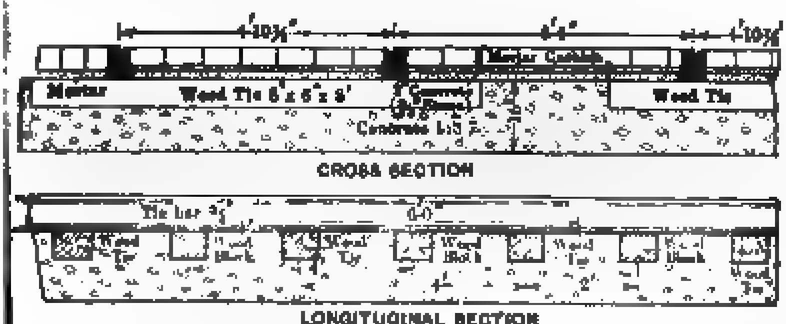


Fig. 35

Fig. 36. Cleveland

Fig. 37. San Francisco

adjacent to the rails; when the rails are at the side and the railroad area does not form a part of the roadway proper, loose broken stone or gravel may be substituted for the stone blocks or brick."

American Practice. Figs. 36 to 47 show types of different kinds of track construction in different cities of America see (22b). It will be noticed that the greater number of the rails are of the T-type, and that the groove is formed in different ways, sometimes by cutting the blocks themselves, and at other times by laying the blocks under the head of the rail, crowning them to the center. While this practice might be satisfactory from the railroads' standpoint, it does not seem that it should be accepted by the city authorities, as it conflicts so entirely with the principle that the street-car track should be part of the pavement and neither invite nor repel traffic. A pavement would not be permitted on a street with a rut in it 1 or 1½ in deep, even if the edges were bevelled off. By laying a double line of T-rails in a street there are formed practically four ruts, into which traffic will naturally go and to cross which must prove a good deal of inconvenience to vehicular traffic.

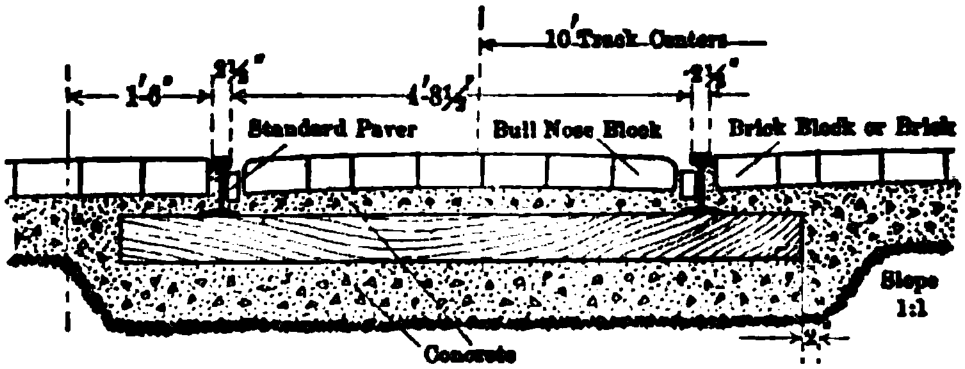


Fig. 38. Seattle

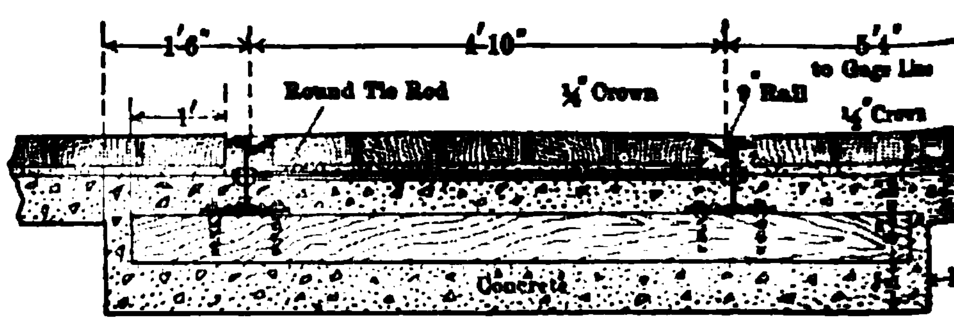


Fig. 39. St. Louis

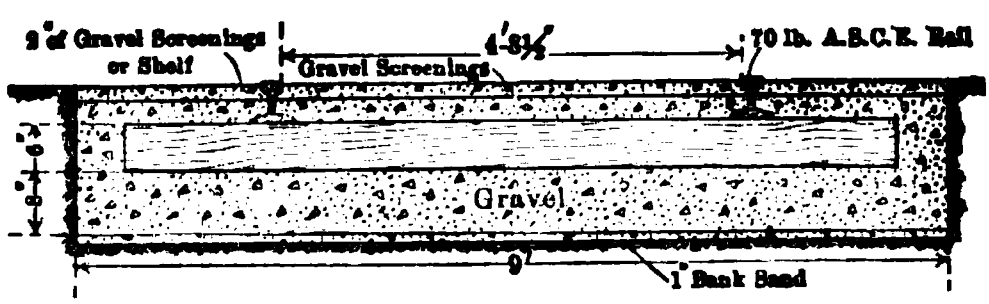


Fig. 40. Houston, Tex.

European Practice in street-car track construction is much like that of the United States, altho as a whole probably not as good. In most places the cars are small and do not require as solid construction. In the larger cities, however, where the double-deck cars are in use, it is essential that the tracks be laid with a great deal of care.

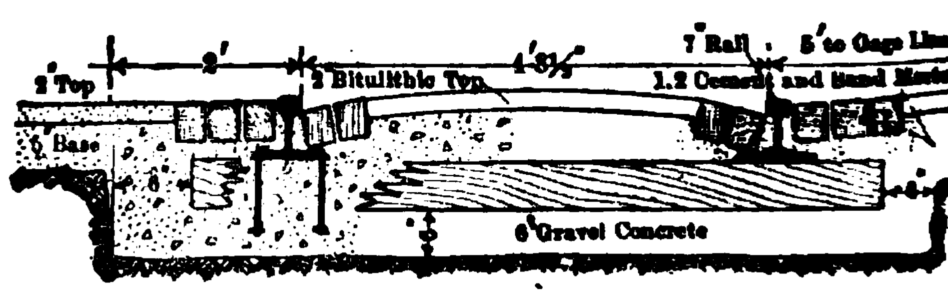


Fig. 41. T-Rail Construction, Dallas, Tex.

La Haye and Geneva, Switzerland, construction is shown by Fig. 48. It will be seen that at La Haye, where the street itself is paved with rock asphalt, wood blocks are laid up against the rail, both on the inside and the outside; also that, while the rail is set on concrete, it is bedded in asphalt in order to get more resiliency. I

Geneva it will be noticed that the rail rests on a chair, which in turn is fastened to a steel tie. Fig. 49 shows the method of laying the rail on a hollow concrete stringer at Geneva. It will be noticed that there is a small base resting upon the concrete stringer.

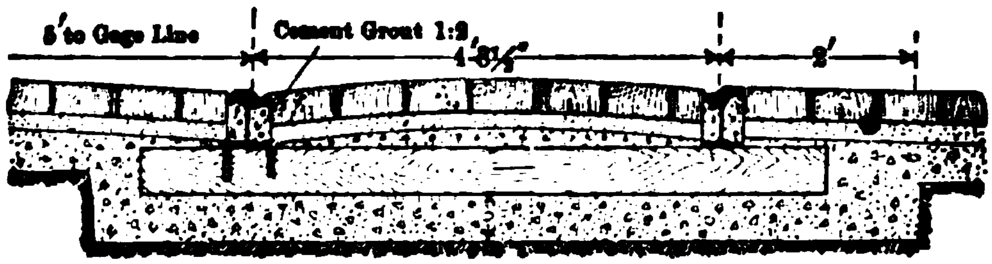


Fig. 42. Girder Rail Construction, Dallas, Tex.

Germany. Fig. 50 shows different examples of steel car-track construction in Germany: A, representing non-rigid construction in Düsseldorf and Berlin; B, semi-rigid construction at Neuchâtel; C, rigid construction at Neuchâtel; D, construction with reinforced concrete blocks at Elberfeld and Brunswick. Fig. 51 is an example of track construction with reinforced concrete in Berlin. It will be noticed from the shape of the rail that it is extremely shallow. Fig. 52 shows a cross-section of track in Berlin with a regular standard rail, the pavement being asphalt. Attention is called to the method of bringing the rail to exact grade by the wedges under the rail itself. Fig. 53 shows a longitudinal section representing clearly the method of attaching the rail to the steel cross-tie, and showing the concrete bearing for the tie itself. Fig. 54 shows track construction with monolithic reinforced concrete at Nuremburg.

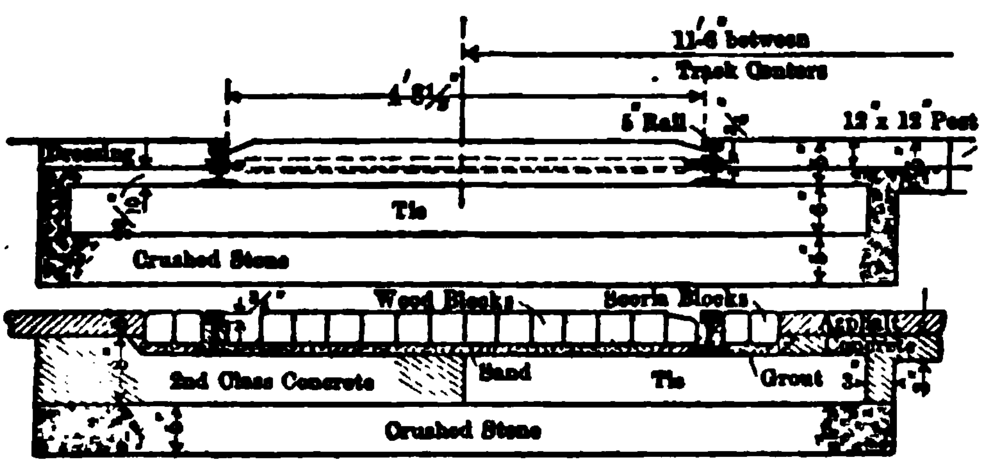


Fig. 43. Capitol Traction Co., Washington, D. C.

Vienna. Fig. 55 shows a cross-section of overhead track construction in Vienna. The rails are set directly in the concrete, and in this particular instance, altho the pavement is rock asphalt, a wood block is set next to the rail. This construction shows the rails laid in concrete, altho sometimes they are set on broken stone. It will be noticed that the rails are tied together by a wide steel bar. Fig. 56 shows underground construction, the slot rail being at the side and serving as a bearing rail for wheels as well as for the slot. The street-railway system of Vienna is owned and operated by the city, and the engineer in charge informed the writer in 1913 that, while he appreciated that the side-slot construction was better for the pavement and for the street, it was not as satisfactory from an operating standpoint. This is probably because it is more difficult to transmit the current thru the side of the car to the underground conduit than thru the center. Side-slot construction was seen in Brussels as well as in Vienna.

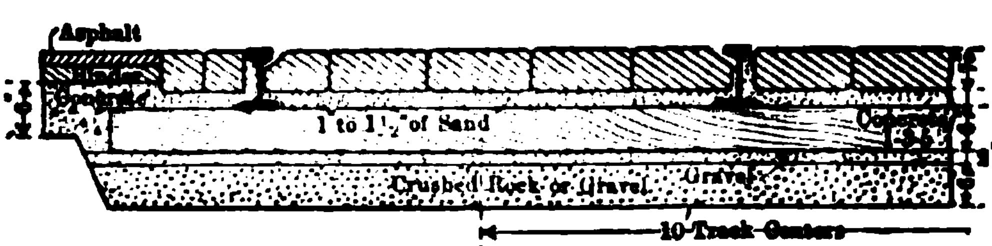


Fig. 44. Minneapolis

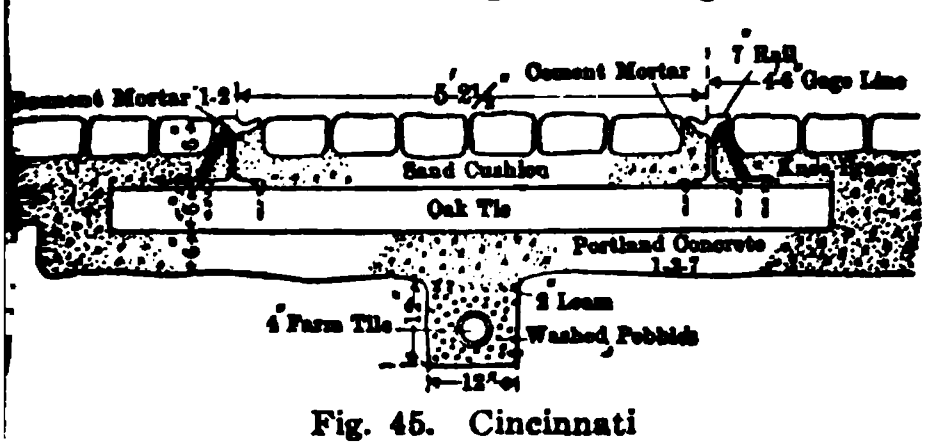


Fig. 45. Cincinnati

Paris. Fig. 57 shows two types of construction in Paris. It might be said in this connection that in 1913 the street-car system of Paris was undergoing many changes. At that time the cars were operated by the overhead and underground electric systems, and also by steam surface cars. The tracks and the pavement between the tracks in many cases were in bad condition. This was said to be because the system was undergoing a change, and it was expected that in 1915 all the lines would be operated by electricity.

Bordeaux, France. Fig. 58 shows a girder rail in concrete in Bordeaux. Here, the rail rests directly upon the concrete, and the rock asphalt pavement is separated from the rail by specially prepared asphalt mastic.

Fig. 46. Buffalo

London County Council. As has been said before, the tramways in London are controlled and operated by the London County Council. They operate both below and above ground, by overhead and underground trolleys. Fig. 59 shows a cross-section of the construction for the overhead trolley. This shows the welded rail joint. Fig. 60 shows this joint in elevation, as well as the methods of reinforcing the rails by what are termed intermediate anchors near the joint. It will also be noticed that there is an extra connection between the rails so as to permit free transmission of the electric current. The engineers evidently recognise that the joint is the weak part of the rail, and provide for extra support as shown. Fig. 61 shows a cross-section of the track for underground construction

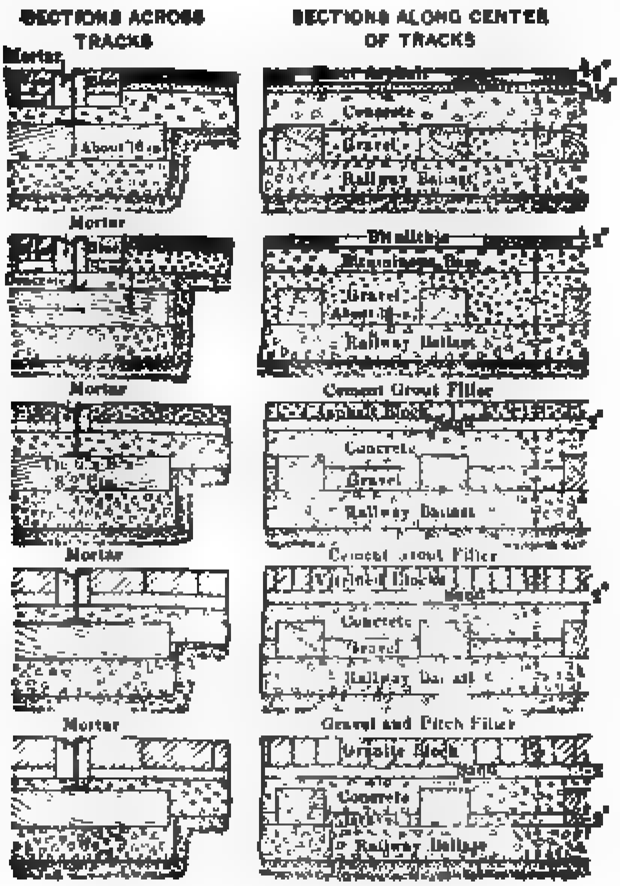


Fig. 47. Baltimore

LA HAYE

Fig. 48

Fig. 49

by what is known as the extended yoke, showing the bearing of the rail upon the yoke itself. Fig. 62 shows a cross-section at a short yoke. Fig. 63 shows a cross-section between the yokes. The extended yokes are spaced 7 ft 6 in center to center and the short yoke is midway between them. Fig. 61 shows a method of making the joint, which varies somewhat from the joint in the track with overhead construction.

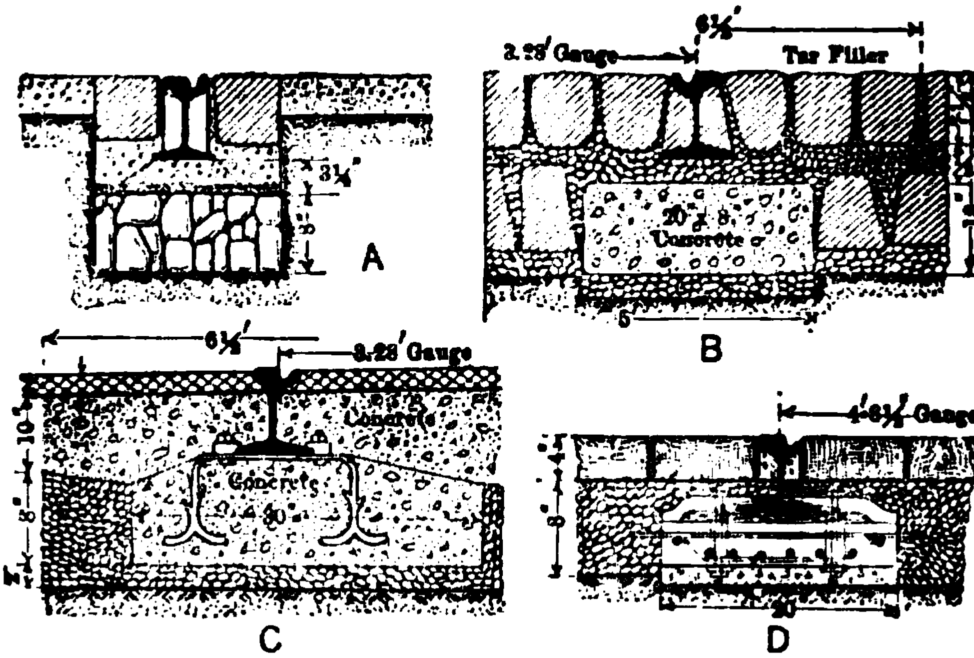


Fig. 50

Construction from Railroad Companies' Standpoint. What has been said before refers to track construction from the city's standpoint. It is interesting as well as instructive to take up the matter from the railroad companies' standpoint, and the question has probably never been better presented than in the 1914 Rep., Com. on Way Matters, Am. Electric Ry. Eng. Assn. (9b). As an introductory to the report, it is stated:

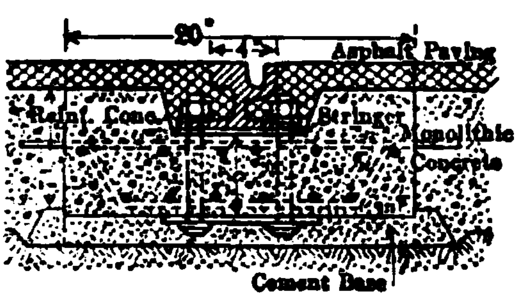


Fig. 51

"The first requirement of all types of structures is permanency. This is particularly true in relation to electric railway tracks in paved streets, where as a rule the types of pavement found are costly and both the railway and the street traffic are heavy, necessitating high expense for all structures occupying such streets when repairs are required. Such repairs then must be kept to a minimum and track structures should be designed with that end in view. However,

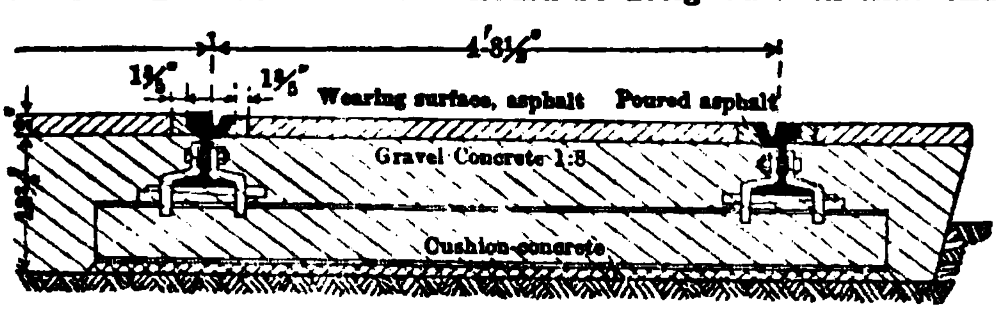


Fig. 52

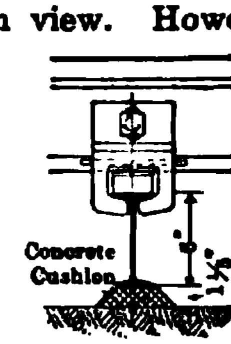


Fig. 53

permanence as applied to railway structures is a relative term and should be understood to mean a state of long durability rather than one of final and absolute fixedness for all time. The permanency of such structures therefore may be considered as meeting the varied requirements if the state of durability is well maintained at the lowest cost per year at the end of a predetermined period of permanency."

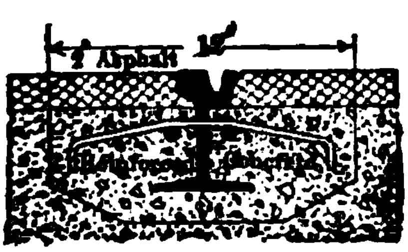


Fig. 54

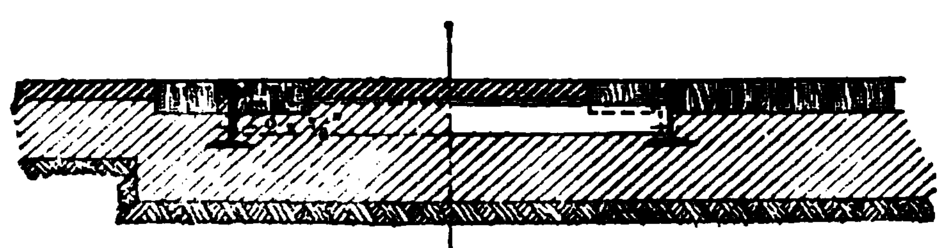


Fig. 55

The Board of Supervising Engineers of the Chicago Traction, in 1909, stated that 20 years was the assumption for the estimated life of track substructure because of the lack of definite information as to life. It was also assumed that the renewal of substructure at the time of renewal of rails would be necessary. The object of the Board was to produce as nearly as possible a permanent structure. The report continues: "As a result of this the board first adopted a solid concrete steel-tie construction without sub-drainage, but quite soon a modification was made by the substitution of wood ties with a closer spacing. After a further experience and partly to provide for unfinished street and subsurface conditions, a stone-ballasted construction, with subsoil drains where necessary, was evolved, and it is now understood that this last type of construction is being used to the complete exclusion of the earlier types. It appears, then, that design may be directed with the view to providing a structure which will be permanent only to the extent of giving durable service with a minimum of maintenance for a period of from 20 to 25 years. It is not only reasonable but also consistent with experience to expect some maintenance expense due to the numerous uncontrollable factors, and the design should be centered upon the lessening of first cost as much as is warranted by the use of first-class materials and workmanship with a type of construction which requires the least amount of expense for repairs."

Fig. 56

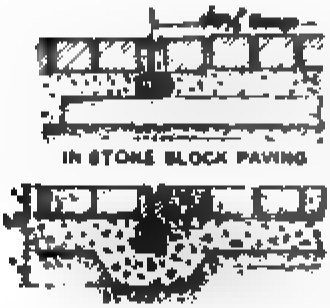


Fig. 57

Fig. 58

Weight of Cars and the Loads and Wear to the Track Construction. The report says: "From statistics in hand it is found that the modern types of prepayment cars, which are coming more and more into use, vary in total weight, fully equipped, from 32 246 to 54 700 lb, and seat an average of 45 people per car, giving an additional weight of 6525 lb if 145 lb per person is taken as average weight. If standing room is considered for an average of 40 people, or a weight of 5800 lb more, the total average heaviest passenger-load per car can be taken at 12 325 lb. Adding this to the minimum and maximum car weights gives a range of load from 44 571 to 67 025 lb."

Fig. 59

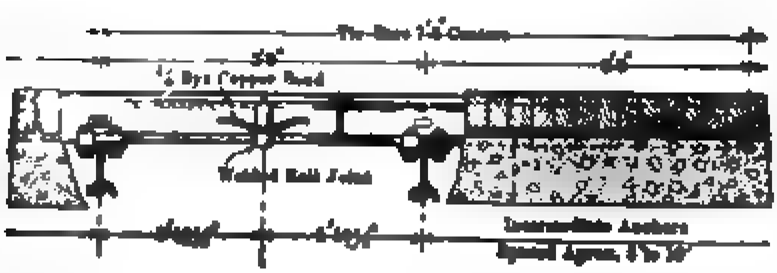


Fig. 60

Ballast. With reference to the ballast used in the substructure, it is stated that only 20% of the roads reporting used concrete ballast, altho it was admitted that the statement might be somewhat misleading, as it was made out on a road rather than a mileage basis.

The ballasted construction was preferred by 60%, solid concrete by 33%, and concrete sub-ballast by 7% of the companies reporting. The report further says:

"The preference for CRUSHED STONE or GRAVEL ballast is stated to be for the following reasons: Lower cost; ease of installation under traffic; provides better drainage; cheaper and easier to repair; concrete too rigid; experience proved it very satisfactory; gives more resiliency to track; good repairs more practicable, concrete too expensive and not generally necessary; makes less noisy track.

"CONCRETE is stated to be preferable for the following reasons: Less liable to give trouble on account of settlements; because we have no cutting under our roadbed; when grade is fixed and all substructures are in place concrete is preferred; for its supporting qualities over excavations; lower maintenance cost; with clay soils."

Fig. 61

It is interesting to note that the report states that neither headway nor speed has much influence on foundation excepting that where joints are poor or corrugation is present in rails the speed undoubtedly adds to the damage resulting from such conditions. And, referring again to the report of the Supervising Engineers of the Chicago Traction, it quotes. "Only the actual weight of the car seemed to affect deflection, and no wave motion in rail existed, for no deflection could be discovered except when the car was actually over the point of reading."

Fig. 62

Fig. 63

Fig. 64

Ties. The report states that the prevailing practice on electric roads calls for 6-in by 8-in by 8-ft ties on 2-ft centers, and that this size and space is considered the best practice. It further states that the proper spacing of steel ties is equally important; that a spacing of 4 ft has been customary, but that it has been found by experiment in Chicago that 3 ft would be more desirable, but that at this point the cost becomes excessive and leads to the use of wood.

Rails. "Deep types of rails are a necessity for work in paved streets and those under 6-in in depth will not satisfactorily provide for most types of permanent pavement. A minimum depth of 7 in is now most preferred, and it is rapidly becoming standard, as is shown by its recent adoption in Boston. Either girder-grooved or T-rails may be used with equally good results, provided a good joint is used. The points in favor of the T-RAIL may be given first, and the chief ones are as follows: (1) The T-

rail is generally considered to be designed on better mechanical lines. (2) More satisfactory mechanical joints can be manufactured, partly because of the symmetry of the rail outline. (3) The flangeway is more suitable for variable wheel flanges. (4) The rails have a longer life as a rule, under equal traffic, with a lessening of street openings for renewals. In theory the life of the ordinary joints is probably longer with a lesser amount of disturbance of pavement at the joint. (5) Many installations of T-rails in paved streets in recent years have satisfactorily met the local conditions. Several cities have required the adoption of high T-rails in replacement of tram and girder-grooved rails. (6) Much objection has been improperly directed against T-rails when it should have been brought against the pavement. This has been proved by the installation of modern pavements with old high T-rails. The points against the T-rails are as follows: (1) It is more expensive per foot of finished track and pavement. (2) Lack of self-cleaning flangeway. (3) Increased wear of pavement adjacent to rails, under extreme traffic conditions, resulting in high paving maintenance. (4) Apt to offer somewhat greater resistance to vehicular traffic. (5) Difficulty in preventing seepage of water in flangeway."

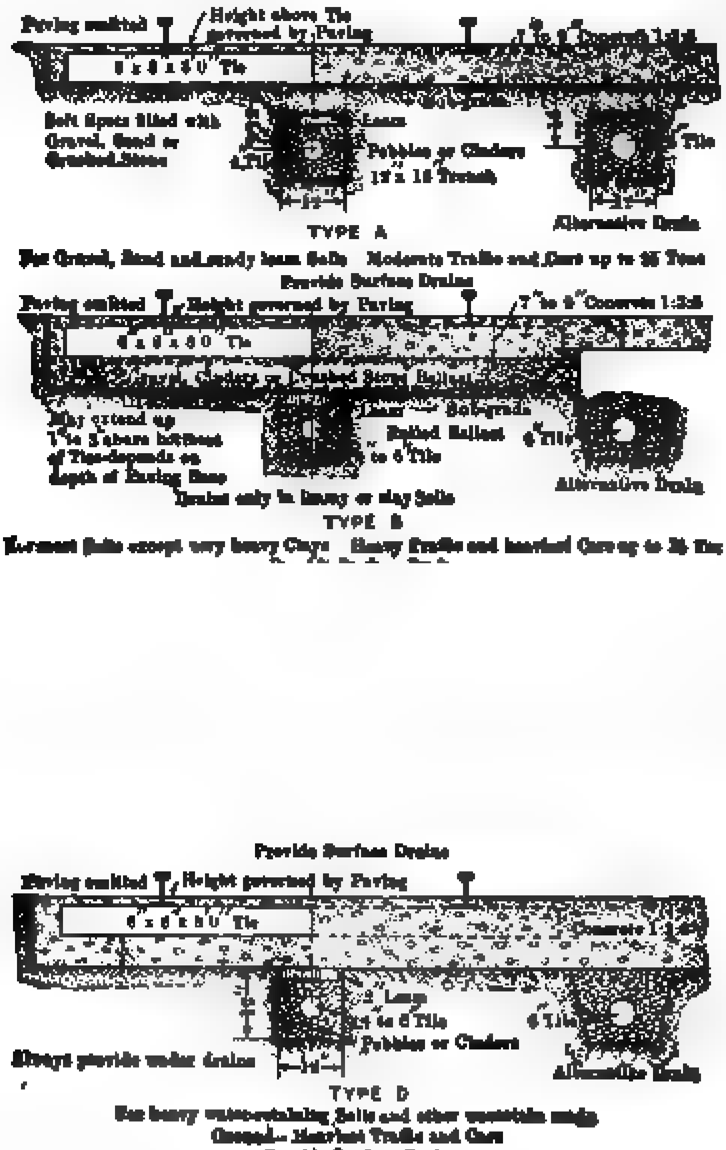


Fig 65

Rail Joints. "The old saying that the life of the joint is the life of the rail" still holds good. It might be extended to include the life of foundation and pavement, as poor joints not only cause rapid destruction of the rail ends but also of the foundation and pavement. The joint question has received much careful study within the past few years, and it is thought that modern electric and cast welds, several combinations of riveted and welded, and at least one improved type of mechanical joint have been evolved which will at least keep joint maintenance down to a reasonable minimum. The general adoption of 60-ft rail lengths has also cut the troubles in two by the simple process of reduction in numbers. The object then is to secure that type of joint which will produce the effect of a continuous rail and at the same time be most available when cost, application and possible repair are considered, altho first cost should not entirely control."

Pavements. Regarding the pavement on the street, it is said that the greatest service to the structure, aside from its own particular duty of providing for vehicular traffic, lies in the waterproofing qualities, and every effort should be directed toward the usage of those pavements which will best prevent the infiltration of surface water. The report finally recommends the FOUR TYPES OF CONSTRUCTION shown in Fig. 65.

Fillers. As regards filler for the head of the rail, the report states that it is difficult to determine; that the general practice seems to be, where the paving block fits under the head of the rail, to pour a cement grout, usually of one part of cement to three parts of sand; where a mortar or plaster is used the proportion may be increased to four parts of sand; that in isolated cases cast-iron fillers are used, as well as wood in other cases; that the preference, however, seems to be in favor of brick, whether the standard paver or a certain type of special brick filler; that concrete block also finds some advocates, but not many, and that asphalt cement grout is used at times where cement grout is omitted.

SUBSURFACE WORK

6. Effect of Subsurface Work on Pavements

The greatest difficulty that an engineer in charge of street pavement repairs has is the replacing of the pavement over cuts made for subsurface work. Repairs necessitated by the wear and tear of traffic can be foreseen and planned for, but a street can be put in first-class condition to-day and to-morrow it may have several openings in it made by the ubiquitous and persistent subsurface companies. This often happens, too, in a new pavement, and there is nothing that is more discouraging to the engineer than, after he has worked hard to have a pavement laid in a first-class manner, to find it opened up in a short time by the subsurface companies. It is true that this is often necessary, but in many instances, by the companies using proper foresight, a large amount of this could be avoided.

Location of Subsurface Work. It is the practice in this country to construct all subsurface work between the curb lines, in the place where it is most difficult and most expensive to connect with, and make repairs to, these structures. About 1890, when a municipality had sewer, water and gas mains laid previous to the construction of a pavement, it could rest assured that not many openings would be made in the pavement in the first few years, especially if the house connections were also laid; but when there exist in city streets, in addition to the foregoing, conduits for electric light and telephones, refrigerating lines, pneumatic tubes, and so forth, new work and repairs keep the streets torn up nearly all the time. Then in our rapidly growing cities, where, as in New York, 20-story buildings are torn down and others of 30 stories erected, and with such structures as the Woolworth Building, with its 55 stories, and the Equitable Building, with its 35 stories, the latter covering an entire block, it is necessary in almost every case to enlarge the subsurface structures in order to supply the increased demand.

The Amount of Disturbance to city pavements due to the work of the subsurface companies is very great. For instance, in the City of Boston during the year ending Jan. 31, 1910, 13 597 permits were issued for the opening of streets for different purposes, and the length of the openings was 151 miles; this was in a total street mileage of 487. In the Borough of Manhattan, New York City, in 1911 there were 25 179 openings made of various sizes, in a total street mileage of 440; in 1914 the area repaved over trenches was 139 865 sq yd, equivalent to practically 8 miles of streets 30 ft wide. In the Borough of Brooklyn, New York City, during the year 1911 the Bureau of Highways relaid pavements over trenches made by plumbers and the different corporations of an amount equivalent to 7 miles of streets 30 ft wide. There were 21 225 openings in Brooklyn in 1914, equivalent to 5.83 miles of streets 30 ft wide. In the City of Chicago, in

the downtown district, in a total street mileage of 20.8, during 1913 permits were given for 4464 openings, making a total yardage of 49 547; while in 1914, in the same area, 1947 permits were issued, covering a yardage of 15 865. In the entire city in 1914, 39 430 openings were made, covering a total yardage of 197 150, or 11.2 miles of streets 30 ft wide. The foregoing quantities are startling, but it is undoubtedly true that the same relative number of openings are made in the other cities of the United States. It may be said that the cost of these openings as a whole is paid by the corporations and not by the city. This is true, but at the same time it is a destruction of property and falls upon the stockholders of the different corporations; and in these days of efficiency and economy it is necessary that everything possible should be done to conserve property, of whatever kind. It must be remembered, too, that the damage done to pavements by the openings is not simply the cost of relaying the pavements actually taken up, but damage is also done to adjacent pavement, which is subjected to an undue and abnormal wear.

European Practice. It is often said that the question of street openings is taken care of in a better way in Europe than in the United States. This is undoubtedly true, but it must be remembered, in the first place, that in almost every case the minor utilities in Europe are laid in the sidewalk area instead of in the roadway. As a general rule, it can be said that sewers and large water and gas mains are the only substructures laid between the curbs in nearly all European cities. Then, too, while European cities grow rapidly, and some of them as rapidly as those of America, they grow in an entirely different way; that is, when a portion of a city is completed, it remains so practically for all time, so that the growth of the cities is from the center outwards, rather than an intensified growth in the center, as is the case in the United States. It is very seldom that buildings are torn down there except when they become old.

Number of Openings. Many openings, however, are made in the city streets of Europe. The Engineer of Westminster, London, informed the writer in 1913 that approximately 20 000 openings were made during the year in 100 miles of streets; about one-half of these openings were made in the sidewalk area and the others in the roadway. He also stated that the minimum size of sewer being built in Westminster was 2 ft 4 in by 3 ft 6 in, so that a workman could enter the sewers when a house connection was necessary and tunnel from the street to the house without in the least disturbing the pavement; also that when openings were concreted just previous to the replacing of the pavement, the concrete foundation was allowed to set 7 days before the pavement itself was relaid. This was true even on the Strand, which is probably the busiest street in Westminster. In Liverpool, in 1912, pavement was restored over 43 miles of trenches in a street mileage of 466, at a time when practically no building was going on. In Glasgow the total number of openings in the street pavements for the year ending May 31, 1912, was 8582, in a total street mileage of 245. In Edinburgh, with its 184 miles of streets, about 5000 openings are made per year. It was not possible to obtain information on the Continent as to the number of street openings, but in Berlin they were said to be negligible. A great deal of time and study has been given to the problem of so constructing subsurface work that its care would not cause such great disturbance of the pavement, but nothing practicable has as yet been worked out in America.

7. Pipe Galleries

New York City Practice. When rapid transit subways were contemplated in New York, the Rapid Transit Board adopted a general plan of construction for pipe galleries in connection with subway work, thinking in this way to obviate some of the trouble. The pipes and conduits to be dealt

with were those of the Department of Water Supply, Gas and Electricity, the mains of the New York Steam Co., the subways of the Consolidated Gas Co., the tubing of the Edison Electric Illuminating Co., and the tubing of the Western Union Telegraph Co., as well as the structures of the Bureau of Sewers. During the year 1896 the companies before mentioned were consulted and satisfactory conclusions reached concerning the location of their structures in the pipe galleries. In 1897 the Rapid Transit Board abandoned its previous work, substituting new plans, which, except as to enlargement at street intersections, provided for galleries of much the same type as the original plans. According to the new plans, an estimate of $650 000 for 2½ miles of construction on Elm St. and Fourth Ave., between Worth and 33rd Sts., was submitted in 1900. After these plans, specifications and details were prepared, the Sewer Bureau objected to its structures being included in the scheme. Its protests were based on the fact that the location of the sewers and the number of other structures above them not only rendered the sewers inaccessible, but made house connections excessively expensive. At the same time the Bureau recommended that the pipe galleries as planned should not be built.

The objections of the Sewer Bureau were later added to by those of the Department of Water Supply, Gas and Electricity, which, while approving the principle of pipe galleries, objected to the size as planned and to having water pipes in the same compartment with gas mains. The gas company had at various times raised objection to having its pipes in any confined space, claiming that such a condition was always dangerous, and, where electrical wires were also present, was especially so. The Chief Engineer of the Rapid Transit Board, on account of these objections, reported that the restoration of subsurface structures at the sides and over the roof of the subway would be possible, and consequently the construction of the pipe galleries was abandoned. At the request of the Merchants' Assn., however, the question of pipe galleries for lower Broadway, Manhattan, was revived in 1902. After much opposition had been presented, including that of the Rapid Transit Subway Construction Co., which objected on the ground that the travelling public would constantly be in danger, it was decided that the galleries should not be built. In 1906 the Rapid Transit Board advised its Chief Engineer to include gallery construction in all work then being planned, and, when in 1907 the question of abandoning certain galleries arose, advised their retention. The year following, approximately 3½ miles of subway construction, all of which provided for pipe galleries, was contracted for. Altho the Rapid Transit Board had at several times considered the combined construction of subways and pipe galleries as applied to various local conditions, the only gallery completed was a stretch of some 2500 ft on Delancey St. Owing to the objection of the gas company to galleries in general, and the objection of the Department of Water Supply to having its structures in the same compartment with gas mains, these galleries have never been used. The Public Service Comm., which succeeded the Rapid Transit Board in 1907, early took up the question of pipe galleries. On the Fourth Ave. subway, Brooklyn, 63 blocks of subway, including 33 000 ft of pipe galleries, were contracted for, and the excavation of the subway prism was started in such a manner that the galleries would be accommodated. However, before the time to begin the construction of the galleries, it was decided that they should be omitted, and in the plans for other portions of the dual system of rapid transit the Public Service Comm. did not provide for pipe galleries.

Chicago Practice. The question of pipe galleries is a matter that has been given a great deal of consideration in Chicago, and on Dec. 31, 1914, Alvord & Burdick, civil engineers, of Chicago, made a progress report to the Commission on Downtown Municipal Improvements on improved means for accommodating pipe utilities in the downtown Chicago streets. In the report it is stated that, as far as the downtown district is concerned, the street congestion below the surface is now comparable with that above the surface, and that it is not sufficient to provide for a greater occupancy

of the business district by improved transportation facilities without providing the means for the convenience of the greater population as provided by the utilities of water, sewerage, gas, electricity and telephone. It is also stated that naturally each utility company, seeing more clearly the cost to which it would be subjected by a change, and less clearly the costs that might be incurred by combination with other utilities, should incline toward solving its own problem for itself, but that for each utility to solve its own problem independently will not work to the best interests of the public, for the public is composed of individuals who to a great extent are rate-payers to all the private corporations and tax-payers as well. So that it was considered the investigation so far made was not sufficient to answer the fundamental questions of practicability and cost, but that the subject should be pursued without delay until these questions are settled.

Financial Problems. In the part of the city studied, that is, north of 12th St. and south and east of the River, there were 20.8 miles of pavements, and beneath these pavements 220 miles of utility pipes and conduit lines, not considering service connections. It would seem, therefore, that there was an average of 10 miles of subsurface structures of some kind to each mile of street. The report says that the utility galleries, to be financially practicable, must permit of a saving sufficient to warrant their cost, and further: "The savings will include: (1) Cost of street openings amounting to $200 000 to $400 000 annually; (2) a reduction in the cost of pavement maintenance; (3) a longer life for pavements; (4) a reduction in the operating cost of utilities; (5) a saving in cost of future extensions; (6) a reduced leakage of water and gas; (7) the value to the public of good streets and decreased interference with travel. The costs will include the fixed charges on: (1) The expenditures for galleries; (2) the cost of moving the utilities to the galleries, taking into consideration that the greater part of the present investment would be economically abandoned; (3) the cost of cutting and reconnecting the service lines. The costs and savings involved can be determined only by further investigation, and preferably thru coöperation with the public service companies. A rough estimate indicates that the reproduction cost of the sub-street utilities, public and private, now existing, lies between 10 and 13 million dollars." This report was made because of the fact that a great many of the streets in this section of Chicago are to be torn up for construction of transportation subways.

Character of Public Utilities. The 220 miles of pipes and conduits in this section are made up as follows: Water pipes, 34.6; sewers, 23.6; clay wires, 5.3; gas company mains, 94.9. Conduits of: Commonwealth-Edison Co., 25.3; Chicago Telephone Co., 24.2; Western Union Telegraph Co., 5.7; Postal Telegraph Co., 6.5.

Housing of All or Part of Public Utilities. The report further states that in considering the plans for housing the public utilities within a subway or underground gallery the question of providing for all or only part of the utilities should be taken into account. The cross-sectional areas of the utilities in certain streets are given, the greatest being on Twelfth St., east of State St., 31.6 sq ft, and a table is given showing how much these different areas would be reduced by excluding the sewers or gas mains, or both. It is concluded that a space 4 ft wide by 7 ft high would be necessary for inspection and repairs; that, even on straight runs where 15 ft would be necessary to house all the utilities, and where 5 sq ft only would be necessary for the same purpose with the gas mains and sewers excluded, means of access would require cross-sections not less than 45 sq ft in the first case and 35 sq ft in the second case, so that, so far as straight runs of conduit are concerned, the saving in cost by the exclusion of certain utilities would not be very great. It is also stated that: "There are other reasons, however, why careful consideration should be given to the exclusion or inclusion of certain utilities. The sewers, except for occasional new connections from premises served, require very infrequent tearing up of the streets, and the other utilities differ in the gain that would come from enclosure within a gallery, except in so far as concerns future enlargements. It is questionable whether a plan could be worked out whereby the electric cables could be accommodated otherwise than within ducts within the gallery with special facilities for admitting the cables at certain intervals. It might be practicable to accommodate the telephone cables

upon shelves or in troughs so that a man could make repairs by removing the cable and laying it upon the floor of the gallery."

Subway Congestion. The following conclusion is given for the relief of subsurface congestion, and is discussed in the report in detail: "The most obvious remedy for the relief of subsurface congestion in the Chicago streets, and the manner most frequently discussed, is the construction of underground subways or galleries permitting of the orderly accommodation of the necessary distribution pipes, conduits and wires. This remedy has been frequently discussed in a number of American cities, and the matter has been given quite a thoro consideration in the more congested cities of Europe. So far as this country is concerned, no actual experience in the matter has been gained; no such subways have been built except for one short street in New York, and, for some reason not fully apparent, this subway is not occupied.".

Sidewalk Space. The following is taken from their discussion as regards sub-sidewalk space: "It is believed that there is ample space between the curb and the property line for the accommodation of utilities on nearly all streets. The utilization of this space for the accommodation of public utilities has several important advantages. It surrounds each block, and therefore intersects the service connection for each utility at the place where new connections can be made with the minimum of expense and with least disturbance to continuous service. This applies to the private consumers and also to the public in forming a ready means of connection to existing fire hydrants, street drainage inlets, street lighting and the police and fire alarm boxes. It is also the location where a continuous passageway, except for street crossings, could be formed at a minimum of expense, for at least one side, and the roof of the necessary passageways is already built on two-thirds of the street frontage in the down-town district, and a greater percentage in that portion of it most needing utility galleries. The necessary construction could be carried on in this place with less interference to the public than in any location except in the alleys. All utilities except the sanitary sewers may be readily accommodated at or above the level of the cellar floors. If the separate system of sewers is adopted, the storm water drains at the upper ends of the branches may lie close to the level of the gutters, and even at their outlets need not be much, if any, below the basement floor level. The very great majority of the sanitary sewage will be intercepted at or above the level of the first basement floors. In the multi-story basements of the most modern buildings the sewage must be pumped with any practicable location of sewers."

European Practice. In 1910, Nelson P. Lewis, Chief Engineer, Board of Estimate and Apportionment, New York City, made a report (6a) on the subject of subways in European cities, and the following information is taken from that report:

London. In 1861 a pipe subway was constructed in Garrick St., 300 ft long. This subway was 7½ ft in height and 12 ft in width, in addition to which there were 14 arched side passages for house service pipes. In the creation of Southwark St., on the south side of the Thames, in 1864, Commercial Road in 1868, Queen Victoria St. in 1870, Northumberland Ave. in 1876, and other subsequent improvements, provision was made for the inclusion of pipe subways in the original construction of the streets. The cost was therefore reduced to a minimum, that of subways approximately 12 ft in width and 7 ft in height having varied from $17.08 a lin ft in the case of Garrick St., to $40.00 a ft in the case of Rosebery Ave.

The pipe subways in the City of London are partly under the control of the London County Council and partly under that of the Corporation of the City of London. The length of the subways under the control of the London County Council is 35 940 ft. The rates charged for the use of these subways are arbitrary and not always in proportion to the length of the subways. This is particularly true in the case of small pipes, the annual charge for those under 3 in in diameter being $5 for the subway in Garrick St., 300 ft long, as well as for that in the Victoria Embankment, which is 6690 ft long. For pipes 3 in and under 6 in in diameter the rate is $10 for the Garrick St. subway, and $25 for the Victoria Embankment, so that, altho the latter is 22⅓ times as long as the former, the charge for its use is but 2½ times as much. As the sizes of the pipes increase, however, this discrepancy in great measure disappears. For instance, for pipes over 36 in in diameter the annual charge for the Garrick St. subway is $15, while for the Victoria Embankment it is $250. The foregoing rates

are the "annual charge for water and gas companies having power to break up streets." A sharp distinction is drawn between companies having this power and other "companies, bodies or persons," for which latter the charge for occupying the entire subway appears to bear some relation to its length and is also at a higher rate. For this class of pipes the annual charge for those under 8 in in diameter for the Garrick St. subway is $10 and for that under the Victoria Embankment $150, while for pipes between 12 in and 18 in in diameter the annual charge for the Garrick St. subway is $25 and for the Victoria Embankment it is $420.

The subways under the control of the CORPORATION OF THE CITY OF LONDON occupy 15 different streets and have a total length of 8124 ft. In these subways there are 10 194 ft of water mains, 12 689 ft of gas mains, 5 049 ft of hydraulic power pipes, and 9 389 ft of pneumatic tubes. In addition to these pipes there are 34 416 ft of electric conduits, varying from small single cables to troughs, or boxes, 6 by 36 in, and including 168 ft of conduit in trenches beneath the bottom of the subways. The schedule of charges for the occupation of subways under the control of the Corporation of the City of London is the same as that fixed by the London County Council for water and gas companies having power to break up the streets. There is no schedule for other companies. The report says: "From the data already given it will be seen that the total length of pipe subways now in use in the City of London is 6.346 miles, altho London began building these subways in about 1861. In explanation of the very limited mileage which had been constructed, I was informed that it is only when a new street is created or an old street is widened or straightened that any attempt is made to build pipe subways, and that the expense of constructing them in existing streets simply for the accommodation of underground structures would be so great as to be out of proportion to the benefits to be derived."

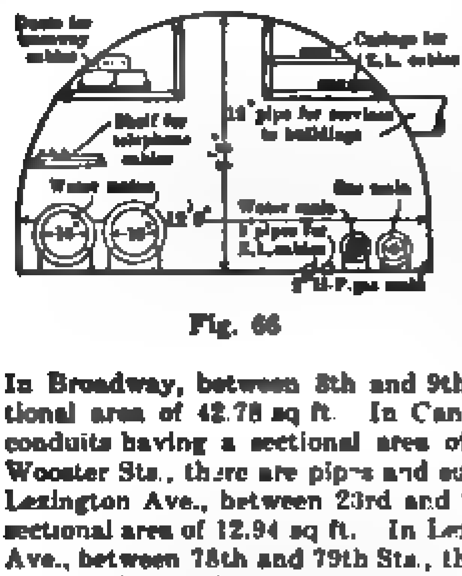


Fig. 66

Comparing the SPACE OCCUPIED by the London subways with the cross-sectional area of the pipes and conduits in New York, Lewis says that he selected three typical subways in the busiest streets of London, all being 12 ft in width and 7½ ft in height. The subway under Holborn Circus contains pipes and conduits with a sectional area of 5.88 ft. In Monument St., the total sectional area is 8.1 sq ft. In the conduit under Shoe Lane the total sectional area occupied is 9.83 ft. In Broadway, New York, between Walker and Lispenard Sts., there are pipe subways having a total sectional area of 46.3 sq ft. In Broadway, between 8th and 9th Sts., there are pipes and conduits having a sectional area of 42.78 sq ft. In Canal St., east of Mulberry St., there are pipes and conduits having a sectional area of 26.88 sq ft. In Canal St., between Greene and Wooster Sts., there are pipes and subways having a sectional area of 42.53 sq ft. In Lexington Ave., between 23rd and 24th Sts., there are pipes and conduits having a sectional area of 12.94 sq ft. In Lexington Ave., between 78th and 79th Sts., there are pipes and conduits having a sectional area of 17.85 sq ft.

Fig. 66 shows a cross-section of one subway constructed by the London County Council, and Fig. 67 the one constructed in the Victoria Embankment. These cuts are taken from the report of L. A. Dumond, of Chicago, made to the Commission on Downtown Municipal Improvements.

Nottingham, England. This city in 1910 had a population of about 250 000 and had constructed pipe subways in new streets since 1861 aggregating about ½ mile.

Fig. 67

Gas and electric conductors, as well as other pipes and mains, are placed in the subways, and the sewer constructed beneath the center of the subway, which is 10 ft in width and 8 ft 6 in in height. This subway cost, not including the sewer, subway

vaults, or connections, about $17 per lin ft, the work having been done in connection with the construction of a new street. In the report a quotation is made from a paper presented by the Borough Engineer, which reads as follows: "To show the value of such works in the street called Victoria St., in which is situated the general post office, there are, besides the gas and water pipes and connections, no less than six pipes containing telegraph wires in this subway, and not one single stone was disturbed in this carriageway for 25 years, and in that period not one single penny was spent in repairs on the street."

St. Helens, England. In 1910 it had a population of about 95 000 people. It has constructed a subway 6 ft 6 in in height, 5 ft 6 in in width, and 2040 ft long. It is constructed entirely of concrete, with the exception of one ring of brick on the inner side of the arch, the upper part of the concrete forming a foundation for the pavement of the street. It is provided with 6-in earthenware pipes, running beyond the curb line at frequent intervals, in which the gas and water service pipes are placed. The cost of the work, including lateral connections and electric light, is said to have been less than $12 per lin ft, but the work was done in connection with the entire reconstruction of the street. The Engineer stated in a personal interview that so far as he knew not a paving stone in the roadway of the streets occupied by the subway had been disturbed since its construction 11 years before. He regarded it as a success, but as expensive, and stated that there was no present likelihood of the construction of any more subways unless it might be under similar circumstances and in connection with the building of a new or the widening of an existing street.

Glasgow. This city has a subway 345 ft long, 6½ ft wide and 7 ft high, constructed in 1905. Seventy-three cross-connections, consisting of 12-in fire-clay pipe, were laid from the subway to the curb line, and the cost complete, including the connections for the service pipes and electric lighting, was somewhat less than $18 a ft. This subway was not built in connection with street reconstruction, which probably accounts for its increased cost over the subway of practically the same size at St. Helens.

Milan. This city has one street, the Via Dante, where subways have been constructed on each side 6 ft high by 4 or 5 ft wide. These subways are laid adjacent to the foundation walls. Lewis states that when he visited the city in 1910 one side of the street was open for a considerable portion of the length occupied by the subway for the purpose of laying a new gas main, but he was unable to ascertain whether this was on account of the lack of room in the subway or doubt as to the safety of placing a gas main therein.

These are all of the European cities that have specially constructed pipe subways, and the total length, exclusive of Milan, which is not given, is practically 10 miles. They have required more than 50 years for their construction, and they have been constructed, with the exception of Glasgow, only in connection with the laying out of new streets or the reconstructing of old.

Physical and Financial Problems. In considering the general subject of placing all underground conduits in subways it must be remembered that there are two problems to be studied, physical and financial. In all of our large cities underground structures have already been laid, and the problem of dealing with them is very different from what it would be were one about to plan a new city; and even then the experiences in New York, in attempting to combine them all in one subway, would indicate that the problem is not a simple one. The different corporations are jealous of their own interests, and it is extremely difficult to harmonize them so that they can be treated as a whole. If all underground construction work were owned by the city, then the problem would be simply a question of finance, as, if it were deemed advisable, the different departments could be directed to lay their pipes as the authorities deemed best. It seems extremely improbable that it will be possible to arrange in a practical way for the grouping of all subsurface work in one or more subways in the same street. Admitting, then, this to be so, the question is to handle the making of repairs and the work of new construction in such a way as to inconve-

nience the public and damage the pavements as little as possible. That can be done by requiring that all subsurface work shall be carried out in accordance with certain rules and regulations. It should be understood that the streets are for the use of the public and that if it is necessary for any corporation to obstruct them such corporation should be willing to bear considerable expense and inconvenience so as to protect the public. Rules can be made that a pavement shall not be opened for a certain length of time after it has been laid, but when leaks occur in sewer, gas or water mains they must be repaired or the pavements will be damaged more than if left alone.

8. Prevention and Restoration of Pavement Openings

Admitting that pavements must be opened frequently, the problem is to reduce the number of openings to a minimum and so safeguard them that there will be as little obstruction to traffic as possible. Precautions relative to the prevention and restoration of openings are absolutely necessary in the built-up sections of cities where mains of various kinds have been laid and no records kept of their location, but in the growing sections of a city there is no necessity of new construction being placed between the curbs. The city owns the street from property line to property line, and the sidewalk area can be utilized to a great extent for many subsurface conduits. It is particularly desirable, even in the suburban districts, to have the streets free from poles and the wires placed underground, but when this means that an opening shall be made in the street for every house connection and for necessary repairs, the gain is attended with considerable loss. It would seem that it would be perfectly feasible for the different subsurface companies to construct service mains in the sidewalk space, connecting at the end of the block with their mains, so that house connections could be made without interfering at all with the roadway surface. In Brussels electric lines are run to tall poles and from there to the different buildings, so that street openings are not often necessary. One sewer connection could be made to a main in the center of a block, and then the different houses could be connected with this sub-main. If objection were made to the fact that these different connections are maintained by the property owners, it could be said that their maintenance might be taken over by the city at less expense than the cost of the extra repair to the pavements due to openings for the connections. In some cases in the outlying districts at the present time the telephone wires are erected on poles placed in the rear lots on the property line and from there connected with the different houses. It would seem to be entirely practicable, if the matter were taken up by the city authorities and the different utility companies in the outlying districts, to construct their systems so that openings in the pavements could be reduced very much below what they are at the present time. Objection might be made by the companies that laying the pipes under the sidewalks would require two lines, but in each case they would be smaller and the expense of opening the street done away with, so that it is questionable if the ultimate expense would be any greater.

In Cincinnati, Ohio, an ordinance prohibits the tearing up of new streets within 3 years after the time of their construction, macadam roadways being excepted. The ordinance provides for 90 days' notice of contemplated street construction to property owners and to public service commissions and also to the director of public service, who is required to compel the laying of sewer and water pipes before streets are constructed. Failure

of the property owners to get notice of the proposed improvements or failure to put in the underground accessories in advance will not be accepted as an excuse for permitting them to tear up the streets after they have been built. The ordinance applies to all streets to be improved after its passage which are not already under construction. The measure also provides that if property owners do not have service connections laid from the sewer and water mains to the curb the city will have this done and collect the cost from the property owners in the same way that sidewalk assessments are collected.

New York City. Probably no other city in the world has a greater maze of substructures in its streets than the City of New York. These substructures consist of sewers; water mains; gas mains; elevated column foundations; conduits, conveying electric current for light and power; telephone conduits; conduits conveying electric power for the operation of the various surface railroads; mail tubes thru which mail is distributed by compressed air to the various railroad terminals and the substations of the general post-office; police and fire alarm conduits; conduits conveying the inshore ends of the transatlantic cable lines; steam pipes of the New York Steam Co., conveying steam for heat and power; refrigeration pipes; pipe lines of the oil companies; vaults under the sidewalks; private tunnels, connecting properties on opposite sides of the streets, conveying light, heat and power, etc. Substructures of this character have been accumulating for years in the principal thorofares in this city, and, unfortunately, little is known relative to their location or size. In consequence, it has become a fixed practice, preliminary to the installation of new structures, to resort to pavement mutilation by digging test pits in order to determine a feasible location. These test pits are dug at intervals of about 100 ft, and frequently pavements on several thorofares are mutilated in this manner before a satisfactory route is determined. This mode of procedure is at best only a makeshift as long as the intervening space remains a mystery. When the work is in progress and this space is uncovered it is not unusual to find unlooked-for structures of such importance that to avoid them special construction must be resorted to. This practice delays the work, keeps the thorofare obstructed for a greater length of time, results in additional pavement mutilation and increases the cost. The most important subsurface work ever carried on in this city was the construction of the elaborate system of passenger-carrying subways, which in many instances occupy the entire width of the streets. Provision had to be made for practically all substructures encountered; in consequence, it was necessary to prepare subsurface record maps in advance of the work. These subsurface records were used in connection with the actual designing of the structures and were made a part of the contract drawings, giving the prospective contractor much valuable information as to the type and character of the substructures to be cared for during construction. This, without doubt, resulted in a material saving in the cost of the work. In New York City the Board of Estimate and Apportionment will not authorize the paving of any street unless water and gas mains and sewers have been constructed. In the Borough of Brooklyn, the Sewer Bureau includes in its work for the sewer proper the laying of house connections within the curb line in front of each lot.

Borough of Manhattan. The following rules have been adopted to be observed by parties making openings in the pavements, it being recognized that when openings are made they must be repaired as soon as possible.

"The Applicant Agrees to comply with all the rules and regulations printed upon the back of or referred to in this application, as well as all other laws and ordinances relating to such work; and the acceptance of the permit shall be deemed an agreement to abide by all of its terms and conditions as herein set forth.

"Deposit. A public service corporation may make a cash deposit or give a bond and make an additional smaller cash deposit in advance, an amount which in the opinion of the Commissioner of Public Works shall at all times be sufficient to cover all expenses to the city as above set forth; provided, however, that the Commissioner of Public Works may discontinue such arrangement at any time and require a specified charge for such opening. The City of New York shall not be liable for any interest on deposits made as provided in any part of this permit.

"Yardage Rate. The charge shall be based upon an arbitrary rate per square yard. Should a settlement occur in the restored area or other defect develop therein within 6 months from the date of restoration, which in the opinion of the Chief Engineer in charge, after proper notification of and conference with the permittee, was due to improper workmanship below the pavement itself, the Borough President, on behalf of the City of New York, will again replace the restored pavement, the cost of such restoration to be charged against the permittee.

"Time Limit. In case the work has not been completed before the day of expiration as shown in the permit, the Borough President may, if he deems necessary, take steps to backfill the trench and replace a permanent pavement over the opening for which the permit has been issued; and if an extension of time beyond said date is needed for the completion of the work, a new application must be filed.

"Subsurface Plans. Upon the completion of the work the permittee shall furnish to the Commissioner of Public Works plans of such character as he may direct, showing accurately and distinctly the location, size and type of construction and complete dimensions of the structure installed. The depth below the street surface of the new structures must be shown; also their location with reference to the nearest curb line and curb intersection. No refunds will be allowed by the Commissioner until such plans have been submitted.

"Excavation. The work shall be so conducted that the water mains or service connections, the sewers or house connections, shall not be interfered with. All rock within 5 ft of a water main shall be removed without blasting. No excavation shall be made within 4 ft of the trunk of any tree without the approval of the Park Commissioner.

"Backfilling. The applicant further agrees to replace, as far as possible, all material excavated, making use of flushing, tamping or other means to accomplish this end, and supplying any deficiency; and that in case the inspector shall deem the material unsatisfactory for backfill, and this decision shall be concurred in by the Chief Engineer of the Bureau of Highways or duly authorized assistant, then the applicant shall backfill the trench with sand, hard-coal cinders or other proper material, removing all excess of original material from the premises. If tamping alone is employed, the material shall be replaced in layers not to exceed 3 in in thickness, each layer being tamped so as to be as thin as possible.

"Planking. Upon completion of the backfill, the applicant further agrees to lay in the cut in the pavement temporary planks of suitable thickness and quality, all securely fastened together, or, if permitted in writing, other material satisfactory to the Commissioner of Public Works, such as hard-coal cinders wetted and heavily tamped, all properly supported so as to bring its top flush with the pavement surface.

"Final Restoration. At the time of making the repair the concrete base shall be removed for a space at least 6 in larger on all sides than the dimensions of the trench excavated, all old concrete work to be properly grouted, and fresh concrete laid so as to secure a good bond with the old concrete and a firm foundation on the untouched sides of the trench. The portion of the pavement which rests upon the new foundation shall be replaced by the city over an area 6 in larger on all sides than the area of the new concrete above described; all of such work being done in order to secure a proper bond and to prevent improper settlement.

"Notice to Bureau of Highways. The Bureau of Highways shall be notified 4 working hr before the time when the opening of the pavement is to be made, so that an inspector of the Bureau may be present, and until such proper notification has been made no opening in the pavement shall be undertaken unless special permission,

in writing, is given by the Borough President to make such without the presence of an inspector. The Bureau of Highways shall also be notified 4 hr before completion of backfill so that proper orders may be issued for permanent pavement replacement. If, after proper notice has been given the Bureau of Highways and acknowledged by it, an inspector has not visited the work, the permittee may proceed therewith."

The Borough of Brooklyn is one of the largest boroughs in the Greater City of New York, with an area of 77 square miles, a population rapidly approaching the 2 000 000 mark, a highway system of practically 1200 miles and 900 miles of sewers. Municipal authorities for years have recognized the necessity of a more systematic control of subsurface conditions, and during the latter part of the year 1906 a moderate appropriation was obtained by the President of the Borough of Brooklyn, to be used in establishing a Division of Substructures, to be attached to his office.

Work of the Division of Substructures. The work was put in charge of a competent engineer, with the following objects in view:

1. Accumulating all information obtainable as to the size, location and character of structures under the streets and avenues of the Borough, and recording the same on durable maps.
2. Assigning definite locations for new substructures.
3. Reducing pavement mutilation to a minimum.
4. Conserving as far as possible for future utilization subsurface spaces which are rapidly becoming one of the city's most valuable assets, and from which substantial revenues will be derived thru future franchise grants.
5. Furnishing to applicants seeking subsurface space for tunnels, pipe lines, etc, information as to the location and size of existing substructures. Such information is required by the Board of Estimate and Apportionment when applications are filed for franchises.
6. Furnishing other city departments with information to be used in connection with the location and construction of subways, sewers, water mains, etc.

Details of Record Maps. Preliminary to preparing the subsurface record maps it was decided to adopt a system whereby the maps could be prepared in any section of the Borough without consequent confusion and duplication. The large area to be covered was divided into twenty sections and each section treated separately. The sections are numbered 1 to 20. Record maps are plotted on a durable cloth-mounted paper in sheet form, 32 in wide and 42 in long, to a scale of 20 ft to the in. These dimensions provide amply for a city block length of 800 ft and are the maximum size sheet that can be readily handled. The next step was a systematic arrangement of record maps so as to cover economically a section or part of a section. In other words, the preparation of a record map layout. This was accomplished by using templets of tracing cloth and applying them to a large-scale city map. The city atlas drawn to a scale of 100 ft to the in was used. Tracing-cloth templets cut to a scale of 100 ft to the in correspond in size to the record maps which are plotted to a scale of 20 ft to the in. Consequently, the area covered by a templet on the city map is the same as the area covered by a record map on the ground. With care and ingenuity excellent results are obtained and a record map layout is prepared, using the minimum number of maps to cover a given area. The outline of the streets in the area to be covered by the record maps is inked in on the templets and they are laid aside for future use, which shall be described later. With this method it is possible to make subsurface investigations, prepare record maps in any locality, and obtain a systematic record of such operations. The record maps are numbered consecutively in accordance with the section in which they are located, that is, a record map numbered 1–25 would mean that it is a record of subsurface investigations taken in section No. 1, over an area covered by record map No. 25. This system of section and record map numbering permits of a comprehensive filing system, as all information is filed in accordance with its section number and record map number. In sections of the Borough where the street system is extremely irregular and made up of two or three rectangular systems cut thru by an important diagonal thorofare, a record map layout is determined, covering the important thorofare. The problem presented in

making this layout is to cover by not more than one record map complicated street intersections, thereby avoiding splitting up these intersections, which would necessitate plotting part on one record map and part on another. With a determination of a systematic layout covering this thorofare, a layout is next determined for the adjoining rectangular systems, which usually presents but few difficulties.

Surveys and Investigations. Upon the completion of a record map layout, surveys and investigations are made on the ground. The surveys are made from the established base lines and include the location of curb lines, building lines, car tracks, hydrants, manhole covers, corner basins, gas drips, elevated railway columns, poles and, in fact, any object on the surface that will serve as a guide in determining the size and location of the underlying structure. These locations are obtained by right-angle offsets from the base lines. The stationing of the offset points on the base line is determined by the use of an optical square. This small instrument has proven to be a great time-saver. Upon the completion of the survey within the area covered by the record map or maps to be prepared, investigations are made of all manholes. The usual procedure is to investigate sewer manholes and appurtenances first. Using a specially designed sewer rod, the depth and size of the sewer is determined from the street surface and the type of construction and condition noted. The corner basins are surveyed in a similar manner. It is often necessary to flush corner basins from the near-by hydrants to determine, particularly at street intersections, into which sewer they empty and obtain an approximate location of the connection. Unfortunately, the records of sewers constructed in the older section of Brooklyn years ago are in some instances missing and in other instances so incomplete as to be of no practical use. The manholes of other structures are taken up in turn, the iron covers removed, and full measurements taken, showing the location and size of the conduit line or pipe line entering and leaving the manhole. In the case of the large manhole or junction boxes of the electric companies a special extension rod is used for taking the various measurements. By use of this rod it is possible to obtain practically all the measurements from one position in the center of the manhole. These investigations afford a fund of accurate information as to the size, depth below the surface, and location of substructures at frequent intervals in the thorofare under investigation. The direction taken by pipes, conduits, etc, between manholes is often disclosed by the outline of a strip of pavement relaid after the installation of a new structure or repairs to an existing structure. Locating these traces of pavement cuts is part of the work of the survey party. All irregularities, such as broken manhole covers, clogged sewers or corner basins, broken hydrants, gas-laden junction boxes, etc, are noted and brought promptly to the attention of the city department or public service corporation responsible. While these surveys are under way a representative is sent to the offices of the different public service corporations and city departments for all information obtainable relative to substructures maintained by them in the city thorofares. This information includes test-pit records, general location of structures, standards of construction and plans of special work installed over the area under consideration. The record maps are then plotted. The maps are laid out in strict accordance with the outline of the area to be covered as shown on the templets previously referred to. The survey notes are accurately plotted and checked, including all information from the offices of the public service corporations and city departments. The plotting of these maps is the most important part of the work, as it involves so much troublesome detail. All surface locations, such as building and curb lines, trolley tracks, manhole covers, etc, are shown in black, while the various substructures are shown in distinctive colors: electric light and power conduits are shown in red, gas pipes in green, water pipes in blue, telephone conduits in brown, etc. In consequence, it is not a difficult matter to trace out a run of any particular pipe or conduit line. Water colors are used for the reason that it is necessary from time to time to make corrections to conform with changes constantly taking place, and erasures can be made with but slight injury to the paper.

All Applications for Permits to make new installations and repairs to existing structures are referred to the Division of Substructures for criticism, prior to the issuance of permits. In this way the engineer in charge is kept in close touch with such work, and pavement mutilation and interference with existing structures is materially reduced. During the progress of the work measurements are taken on the ground, relative to the location of the new structures, and all structures encountered. This

information is filed in accordance with the number of the section and number of the record map covering the area in which the work is located. If a record map has been prepared covering the area, the information is plotted by a draftsman assigned to the special work of correcting record maps, thereby keeping them up to date.

Locations and Drawings for New Installations. While definite locations are frequently furnished for new installations, much work has been done in connection with the preparation of subsurface drawings in advance of public work of importance, such as the construction of passenger-carrying subways, trunk sewers and the installation of large water mains. The subsurface information accumulated is used in preparing the construction plans and is also made part of the contract drawings. Probably the most extensive investigations were made in advance of the installation of the large water distribution mains, a part of what is known as the Catskill Water Supply System.

Value of Division. While it is a difficult matter to calculate dollar by dollar the saving involved by this systematic procedure, it is conservatively estimated that the saving is at least equivalent to the entire cost of the Division of Substructures to date. Excellent progress has been made. In the files of the department there has been accumulated a mass of information relative to other sections of the Borough, such as general locations of pipes and conduit lines, private tunnels, test-pit records and construction drawings. This information will be used when the final surveys of these sections are taken up. Similar departments have been established in the other boroughs of the Greater City, using the Brooklyn methods as a basis of operation.

Philadelphia. Undoubtedly, however, the most elaborate and effective steps in the direction of pavement protection have been taken by the City of Philadelphia.

Board of Highway Supervisors. In 1884 there was organized in that city what is known as the Board of Highway Supervisors under an ordinance passed in March of that year "for the purpose of preventing frequent and unnecessary openings in streets and street pavements; to promote system and economy in repaving over breaks made for underground work." The Board is composed of the Director of Public Works, the Chief of the Bureau of Highways, the Chief Engineer of Surveys, the Chief of the Bureau of Water, the Chief of the Electrical Bureau and the Chief of the Bureau of City Property. The Board is vested with full power, not only to grant original locations to companies authorized by law to lay pipes and conduits, but also to direct their removal and relocation whenever the public good may demand it.

Records and Plans. For the purpose of enabling the Board to act intelligently on applications, a recording and drafting department is maintained where all underground structures are plotted and their sizes, depths, distance from the curb or building lines shown upon plans of uniform size drawn to a scale of 20 ft to the in. Each structure is colored with a conventional tint so that it may be followed on the plans. The ever-increasing demand for space under the street surface makes it necessary that the available cross-section be utilized to the best possible advantage. This, in a measure, is accomplished by grouping the structures as closely together as possible. They are required to be laid in locations parallel with the street line and any continuation of existing work must be laid in the line of the original substructure. These extensions are borne in mind when locations are given for new structures. The accuracy of the records in the drafting room of the Board of Highway Supervisors is so to be depended upon that when sewers, water pipes or other underground structures are to be laid in the streets their location can be determined with sufficient exactness to admit of the perfection of the plans for the work without the necessity of making advance excavation. All applicants for permits to locate pipes, conduits and other subsurface structures are required to obtain plans from the Department records, showing by cross-sections all existing structures in the street. These plans are used by the Board in considering the applications and in fixing the locations. By this means an intelligent supervision is constantly kept of every class of construction placed under the surface of the streets, and the city, by reserving space which may be required in the future, obtains a maximum degree of utilization of the width of the street available for uses of this kind.

Charges for Plans. A charge per lin ft is made by the city to parties obtaining plans and information and the cash receipts are considerably more than sufficient

to maintain the force in the drafting room and the field inspectors, who are sent to see that the locations granted are followed, and to make systematical measurements and daily reports covering structures of every character met with in the excavation. From these returns the plans are constantly being checked, and, where necessary, corrected. In addition, upon the completion of the laying of any underground work, either the Bureau of the city or the private corporation having charge of same is required to return to the Board of Highway Supervisors a complete plan giving the exact location occupied and the sizes and positions of every kind of construction met with during the progress of the work. This gives a complete and valuable record for future reference. The charge for the information is as follows: For furnishing plan indicating all underground structures 5 cents per lin ft for any continuous length in the one street up to 2500 ft, 5 blocks, and 3 cents for each additional foot. Where locations are given on unpaved and macadamized highways a straight charge of 1 cent per lin ft is made on account of the fact that these highways are generally located in the suburban sections and contain but few underground structures. Upon the completion of the work, the Bureau sends an official to make a survey and record the exact location in which the structure is placed, and for this a charge of 2 cents per lin ft is made on every class of street, but in no case is this charge less than $5. That is, if a telephone company applies to the Board of Highway Supervisors for a plan showing the underground structures in a street, covering a length of 1000 ft, they would be charged at the rate of 5 cents per lin ft, or $50 for the plan, and upon the completion of the work the Bureau makes a complete survey of the location of the structure and all manholes, spurs, etc, for which the company is charged an additional 2 cents per lin ft, or $20, so that the total cost to the company for the stretch of 1000 ft amounts to $70; on the other hand, for a length of 5000 ft, the charge for the plan would be at the rate of 5 cents per lin ft for the first 2500 ft, or $125, and at the rate of 3 cents per lin ft for the remaining 2500 ft, or $75, making the total plan charge $200, while the charge for the survey would be at the rate of 2 cents per lin ft for the entire distance, or $100, so that the total cost to the company for the stretch of 5000 ft would amount to $300.

Present Status of the Board. The Board has been working for so long a time and in such detail that it has practically all of the subsurface construction in Philadelphia accurately plotted, so that it can readily assign to any applicant the best location for any new work. In this way the space in the streets is most economically used, as by this system nothing is done in haphazard way, but all structures are located according to a definite plan. The fees referred to at the present time create a fund sufficient to pay all the expenses of the Board, so that it is self-sustaining. Philadelphia is honored by being the pioneer in this work as well as for the results that have been accomplished.

Rules and Regulations of the Board of Highway Supervisors Governing Applications for the Laying of Electrical Conduits, Tubes and Manholes, adopted Nov. 8, 1906, and now (1918) in use:

Applications. Companies, corporations, firms or individuals applying under the general ordinance of Aug. 5, 1886, "regulating the laying and construction of underground wires, electrical conductors, conduits, cables and tubes in the City of Philadelphia," shall file with the Board of Highway Supervisors:

1. (a) An application, in writing, giving full name of company, corporation, firm or individual, together with amount of capital, business address, the names of officers and directors with address; (b) the purposes for which they wish to use the streets; (c) character of conduits, manholes, tubes, etc.

2. At least two copies on Linaura of plans, showing all existing underground structures and complete details of proposed construction.

3. Such other information as may be required to enable the Board to reach a clear understanding of the whole subject.

Agreements. Before any street surface shall be broken, or a permit issued, except as hereinafter provided, the following rules and regulations, and such additional rules and regulations as the Board of Highway Supervisors may from time to time adopt, shall be binding on the applicant or applicants:

1. (a) The execution of bond, etc, to comply with general ordinance; (b) compliance with the ordinance granting special privileges; (c) compliance with the rules of the Board of Highway Supervisors.

2. A certificate from the City Solicitor that the necessary bond and agreement have been filed.

3. A certificate from the City Treasurer that the requisite payments have been made.

4. An agreement from the Contractor, who is under liability for the maintenance of any street desired to be broken, stating that the guarantee will in no way be affected by the breaking of the same.

SPECIAL AGREEMENTS. After the approval of the Board of Highway Supervisors and the issuance of the permit, the terms and conditions of the application and the accompanying plans shall not thereafter be altered or departed from without the consent of the Board previously obtained; except that in cases of emergency, the Chief of the Electrical Bureau may authorize modifications when necessary, reporting his action to the Board at its next meeting.

2. Where a conduit crosses a bridge, a plan shall be submitted to the Chief of the Bureau of Highways, and no conduit laid thereon until such plan is approved.

3. On undedicated streets the consent of the owner or owners shall be first obtained, and affidavits to that effect filed with the Board of Highway Supervisors.

NOTICES. Before any street surface shall be broken, under a permit as above, notice must be given, in writing, by the receiver of the permit, to the Chief of the Bureau of Highways and the Chief of the Electrical Bureau, of the time, place and extent of the proposed breaking; and where a conduit is located on the sidewalk, the District Surveyor shall be notified of the location and the date of commencing the work.

CONSTRUCTION. 1. No portion of any new structure, when in place in the street, except such as is designed to form a part of the street pavement, shall be less than 2 ft below the surface of said pavement, except with the written approval of the Chief of the Bureau of Highways; and the tops of iron structures forming parts of the street pavement shall have a roughened surface with projections rising not less than ½ in, and spaced not more than 2½ in apart, as approved by the Board of Highway Supervisors. All manhole covers upon streets paved with asphalt, vitrified brick or wooden blocks shall be filled with asphaltum or other material to the satisfaction of the Department of Public Works.

2. New work and new structures shall not interfere with existing pipes, sewers, conduits, or other structures, or their connections, except where absolutely necessary, and then only with the previous consent, in writing, of the Chief of the Bureau having charge of such structures. Any modification of existing structures found to be necessary must be made by or under the direction of the Bureau concerned and at the expense of the party having the permit. All necessary supports and protections to existing structures must be promptly supplied by, or at the expense of, the party having the permit, and to the satisfaction of the Bureau concerned. The said party shall erect and maintain and bear the expense of all necessary guards and danger signals, furnish all necessary watchmen to protect the public and the work during its progress, assuming all liability for accident or damage to persons or property that shall occur in the course of or by reason of said work, and agree to save harmless the City, its officers, agents and servants in all such cases.

3. When, in the judgment of the Board, it shall be deemed desirable to employ one or more special inspectors to supervise the work, such inspector or inspectors shall be appointed by the Director of the Department having supervision over the same, and a sufficient sum deposited by the party receiving the permit, with the Chief of the Bureau, for the payment of such service.

INTERFERENCE WITH TRAFFIC. 1. Openings in streets shall be made at such times and places, and be supported and guarded in such manner as, in the judgment of the Chief of the Bureau of Highways, will least interfere with the rights and convenience of others, and interrupt the traffic of the streets no more than is absolutely necessary.

2. Material and tools for construction must not be delivered in the street till needed for immediate use, and then must be so placed as to cause the least interruption to traffic. Not more than 500 ft in length shall be obstructed or occupied at the same time without special authority of the Board.

FILLING OF OPENINGS. 1. All openings in streets must be promptly filled with suitable material, free from rubbish and perishable matter, and thoroly and evenly compacted thruout, by ramming in thin layers while being put in, or by puddling.

The pavement of street or foot walks must then be at once restored with the same character of material, equal in composition and color to match old work, in accordance with the standard specifications of the Department of Public Works, Bureau of Highways, for such class of work, and maintained in good condition, satisfactory to the Department of Public Works, during the time of any existing guarantee, or as required by Ordinance of Councils, but in no case for a less period than 5 years. All permits are issued subject to Ordinances of Councils regulating the paving and repaving of streets.

2. Surplus and condemned material must be removed, and the street cleaned and entirely restored, without delay.

MAINTENANCE OF SUBSURFACE STRUCTURES. 1. All subsurface structures and all surface structures forming part of the street must at all times be kept in good repair. All work and material used in restoring or repairing the street shall be satisfactory to the Department of Public Works, and when notice calling attention to needed repairs is given, it must receive attention within 24 hr.

2. All work and material used in the construction of electrical conduits and manholes must be satisfactory to the Chief of the Electrical Bureau, and any work or material condemned by him must be at once made satisfactory.

FILING PLANS. Immediately after the completion of the work, the party to whom the permit is issued shall file complete plans in detail to a scale satisfactory to the Board, showing the work as constructed, with all previously existing structures encountered during the construction of the work.

PROTECTION OF PUBLIC. Should work necessary to protect the public in the use of the street be omitted or imperfectly performed by the party holding the permit, then after notice the Chief of the Bureau of Highways may cause the work to be done at the expense of the party receiving the permit. Failure at any time to fully and faithfully comply with these regulations, and such further regulations as the Board may from time to time prescribe, or promptly pay such expense as hereinbefore or hereinafter authorized, shall at once work a forfeiture of permits issued, and debar the party from receiving any further permits until relieved by action of the Board of Highway Supervisors.

PERMITS FOR ELECTRICAL HOUSE CONNECTIONS for the construction of manholes on lines of underground conduits already constructed, where such construction is of advantage to the City or the betterment of the system, may be issued by the Bureau of Highways after approval by the Chief of the Electrical Bureau, without reference to the Board of Highway Supervisors. House connections shall follow the line of conduit and not cross streets diagonally.

If, in the LAYING OF WATER OR GAS PIPES, SEWERS, or any other municipal work, it shall become necessary to change the location of any of the conduits, manholes or other structures, they shall be shifted or altered at the cost or expense of the owners, to such places as shall be directed by the Board of Highway Supervisors.

2. Where the City constructs or reconstructs sewers, or lays or relays water pipes, the Company shall maintain its conduits.

DURATION OF PERMITS. No permit will be valid for more than the number of days specified therein, which shall be determined by the Board of Highway Supervisors at the time the permit is authorized; for any subsequent work a new permit must be obtained. Persons in charge of any work on the streets must have in their possession, at all times while so engaged, the permit issued by the Department. All permits shall expire on Dec. 31 of the year in which they are issued.

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SECTION 24

COMPARISON OF ROADS AND PAVEMENTS

BY

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GENERAL DATA

PROPERTIES OF PAVEMENTS

PROPERTIES OF ROADS

METHODS OF COMPARISON

GENERAL DATA

1. Historical Development of Roads and Pavements

Variety of Pavements. Pavements have been laid of a great many different materials, both in their natural state and also combined so as to make an artificial product. There have undoubtedly been more variations in the forms of bituminous pavements than of any other kind, as many hundreds of patents have been taken out for pavements composed of asphalt or coal tar used in some peculiar or particular way. As has been stated

in Sect. 19, stone was the original paving material and used in many different ways. This was natural on account of its general availability and the knowledge of its durability. But so many experiments have been made that it is not possible or profitable to describe them all. Some of the unusual types, however, will be mentioned.

Unusual Types. IRON BLOCKS AND PLATES. On Unter den Linden, in Berlin, in 1877, an iron pavement was laid. This remained on the street until 1890, when it was taken up, and never used elsewhere. The same contractors received permission, in 1888, to lay impregnated wooden blocks capped with steel. The blocks were laid on concrete and the joints filled with some kind of bituminous material. This pavement lasted until 1897, when it was taken up by the contractors and replaced with rock asphalt. The pavement was said to have been fairly durable at first, but after being in use 8 years the steel capping was worn out in consequence of the traffic. The cost of this pavement was about twice as much as for rock asphalt, and, as the price of steel increased considerably after the pavement was laid, its continued use would have involved still greater expense. Iron blocks were laid on Cortlandt St., New York City, about 1865. They were roughened on the surface by hexagonal projections about 1 in in size, separated by similar depressions. This made a rough and noisy pavement, and horses tore off their shoes and slipped and fell frequently, so that after a short trial it was taken up and replaced with stone blocks. In 1885 a hollow iron block about the shape of the ordinary granite block was suggested, the hollow space to be filled with any material that the officials might deem suitable. Another plan was to set hollow iron cylinders closely together on a firm base and fill the interstices as well as the cylinders with concrete, the idea being that the iron would prevent the wear and the concrete give a general smoothness. It is doubtful, however, if this idea was ever carried out to any extent. In Columbus, Ohio, in 1894 an entrance to a railroad freight yard was paved with iron plates cast with pockets 3 7/16 in square on the upper side. Each plate contained 5 full, 4 half, and 4 quarter pockets, so arranged that when set on the street the plates were square and the pockets at an angle of 45° with the length of the street. The plates were bedded on the foundation, and into the pockets were driven oak spikes 5 in high and projecting 2 in above the pockets. At the end of 16 months the blocks showed a wear of about ¼ in. It is said that macadam within the freight yard was renewed in 90 days and sheet-asphalt outside was replaced in 4 months. This pavement, however, would not be practicable on a large scale and was used to a very slight extent.

COMPRESSED MARSH GRASS. In 1898 an experimental pavement of compressed marsh grass was tried in Richmond, Va. The grass was first treated with a preparation of oil, tar and rosin, and then compressed by hydraulic pressure into blocks about 5 in square and bound together with wire. The blocks were laid in the usual way on a street where they were subjected to very heavy traffic. The pavements lasted but a very few months.

GLASS. In 1898 an experimental pavement was laid in Lyons, France, the blocks being made of devitrified glass; they were 8 in square, each one being cut on top into 16 smaller squares so that the finished pavement looked very much like a huge checkerboard. The treatment consisted of heating broken glass to a temperature of 677° C (1250° F), and compressing it into molds by hydraulic force. The physical transformation of the glass is said to be due to devitrification under the Garchy process. This action, however, is more apparent than real, as a chemical analysis shows that after devitrification the glass has the same composition as before. It possesses all intrinsic qualities of glass except transparency. It is said to resist crushing and heavy frosts very much better than before being treated. No pavement of this character has been used to any great extent.

Classification of Pavements. During many years of experimentation roadways have been paved with stone in its various forms and shapes; wood, treated and untreated; rock and sheet-asphalt, bituminous macadam, bituminous concrete, cement-concrete, iron, brick, slag, india rubber, shells, earth, sand-clay, burnt clay, gravel and even glass, leather and hay. As a result of all this experimental work it is generally accepted that there are five standard pavements, namely, those formed of stone blocks, treated

wood blocks, brick, sheet-asphalt and bituminous concrete. Forty years ago not 1 mile of pavement existed in this country that would be considered standard in 1918.

The Value of Pavements to a city or any particular locality is positive and immediate. In actual money, the value of city pavements is very large. In New York City alone there were on January 1, 1915, 2 394 miles of pavement. Assuming the cost of a pavement to be $2.50 per sq yd and the average width of street to be 30 ft between curbs, the cost per mile, including the curbing, will be about $55 000, making a total of $131 670 000 that New York City would have invested in her streets if the pavement were of good character and in good condition. Or, assuming that each street must be repaved every 20 years, to keep the above mileage renewed when worn out would require the laying of 120 miles of pavement each year. Assuming further that the average cost of repairs to these pavements will be nothing for the first 5 years, and only 5 cents per sq yd for the remainder of their life, the total annual expense for the maintenance and repair of the 1915 mileage of New York City's pavements would be $880 per mile, or $1 580 480 for repairs and $4 224 000 for renewals, assuming renewals to cost $2 per sq yd, or a sum total of $5 805 480 per annum to keep the paved streets of New York City in good condition. As a matter of fact, according to the report of the Chief Engigineer of the Board of Estimate and Apportionment, New York City, in 1912 the city appropriated $14 600 000 for repairs, renewals and original pavements. Other cities will have smaller expenses than these, but this illustration shows the necessity for careful study and investigation. An inventory was made of the pavements in the City of New York in 1912. They were supposed at that time to be worth $58 000 000.

Real estate owners, than whom no more shrewd or sagacious men are in business, recognize the value of pavements, and, when they wish to put a piece of property on the market at once and at good prices, always pave the streets with the most popular material. The pavement improves the appearance of the streets so much that the lots not only sell more rapidly but the owner can add to his price more than enough to reimburse him for his outlay.

This was illustrated very forcibly in a section in Brooklyn, N. Y., where a large tract was put upon the market at one time, but first the streets were all improved and the subsurface work constructed, so that property owners not only knew the condition of the pavement in front of their own property but also in the entire section. This was a particularly successful enterprise. In the Borough of Manhattan, New York City, builders will not begin operations on an unpaved street, knowing the difficulty of making sales or obtaining desirable tenants unless the street is well paved.

Increase in Mileage and Change in Character of Pavements. Table I shows the total mileage and the mileage of the different kinds of pavements in use in the cities of Brooklyn, Boston, Buffalo, Chicago, New York, Philadelphia, St. Louis and Washington, D. C., in 1890 and also in 1915. Brooklyn is considered by itself, as it was a separate city in 1890, and New York represents only the Boroughs of Manhattan and The Bronx, as in 1890 they constituted one city. It will be noted that, not only has the amount of pavement increased from 3146 miles in 1890 to 6986 miles in 1915, but that the modern pavements, like sheet-asphalt, brick and wood block have increased much more rapidly. Creosoted wood block pavement, for instance, was not in use anywhere in 1890, and brick only in Boston, Buffalo and Philadelphia, and then to so small an extent as to be almost negligible. If the cities of the Central West were taken into consideration the increase in brick would be a much greater proportion. The increase

in sheet-asphalt shows its wonderful popularity, and it has come into almost general use as the most popular pavement.

Table I

	Brooklyn		Boston		Buffalo		Chicago	
	1890	1915	1891	1914	1890	1915	1890	1915
Sheet-asphalt	10.85	565.99	4.65	22.13	106.03	259.78	9.24	710.46
Stone block	83.90	151.20	69.27	124.24	140.69	23.69	23.10	111.23
Cobble	289.21	4.04	5.95					
Rubble						60.64		
Brick		1.50	0.35	5.25	0.07	37.06		269.37
Macadam	2.81	114.78	204.57	388.82	3.28	14.03	227.01	552.[illegible]
Cedar block							410.29	214.[illegible]
Coal tar concrete								
Creosoted wood block		7.28		6.61				53.91
Slag block		4.26						7.13
Cement-concrete		0.02						40.[illegible]
Bituminous macadam								66.11
Bitulithic				8.02				
Novaculite								2.00
Bituminous concrete								32.16
	386.77	849.07	284.79	554.57	250.07	395.2[illegible]	369.64	2059.[illegible]

	New York		Philadelphia		St. Louis		Washington	
	1890	1915	1891	1914	1890	1915	1890	1914
Sheet-asphalt	16.34	416.58	43.40	511.96	3.95	69.82	51.80	182.96
Stone block	273.75	160.78	119.60	348.32	42.46	68.57	23.50	25.58
Cobble	3.33		375.10	7.13			11.50	4.12
Rubble			115.50	4.63				
Brick		0.04	19.80	171.57		182.21		1.34
Macadam	24.28	127.49	88.80	248.10	290.08	252.06	8.00	122.12
Cedar block					5.26		0.30	
Coal tar concrete							38.21	
Creosoted wood block		38.30		8.16		13.94		
Slag block		1.55		8.13				
Cement-concrete				11.03				1.66
Bituminous macadam				60.96				
Bitulithic						47.05		
Novaculite						8.74		
Bituminous concrete		17.00						6.16
	317.65	761.69	762.20	1379.99	341.75	642.39	133.31	343.94

Totals: 1890, 3146.18; 1915, 6986.17

2. Principles Underlying the Selection of a Road or Pavement for a Specific Highway

In order that the highway official or legislative body ordering roads or pavements may do it intelligently, it is necessary that they should know, not only the properties of the different kinds of paving material, but also the requirements of the highways to be paved. This is not generally understood or recognized. If an architect, or an engineer in any other line

is about to make plans and specifications for a new structure, he first learns to what purpose the proposed structure is to be put, and then, and not till then, can he intelligently decide upon the proper materials for the different portions of the structure. This is just as important in a pavement as in any other structure, but not so easy to obtain. Different officials speak of different kinds of traffic as heavy, medium and light, but these terms have no positive or definite meaning. They are relative wholly, as what is heavy traffic for Rochester, N. Y., might be medium traffic for New York City, and at that the terms would be used only according to the individual judgment of the persons using them. Different schemes have been in use for determining the kind of traffic upon different streets. This is done by counting the number of vehicles passing a given point during a specified time and fixing a certain weight for the different vehicles, and in this way obtaining the supposed amount of tonnage passing over any street during this specified time. While this method is of some value, as giving approximately the wear on the pavement, it is not definite, as no rating is given to the conditions under which the tonnage is carried. It will be easily understood that two loads weighing 10 tons each will have a different effect upon a pavement than 20 tons carried over the same pavement in ten different vehicles. It will make a difference whether the vehicles are horse-drawn or motor-driven, whether the tires are of rubber or of steel, and whether of 1 or 4-in in width, and whether the vehicle is moving at a speed of 4 miles or 20 miles an hr. All these conditions must be taken into consideration in order to get a fair and comparable result of different tonnages borne over different pavements. It will be seen, therefore, that the problem is not a simple one, but one that requires much careful study. Only a few highway departments in the United States, and not many in foreign countries, have any census statistics of their highways that are of value, and, until they have such data, it is not possible to determine from a scientific standpoint the proper roads or pavements for different local conditions. See Sect. 4, TRAFFIC CONSIDERATIONS.

English Road Board Determinator. It would seem, however, that by proper experimenting a traffic unit could be arrived at and so standardized that a more definite result could be reached than is possible at the present time. The English Road Board has constructed a machine for experimental work to determine just what will be the wear on certain pavements by different weights moving on wheels at different rates of speed. The machine consists of an apparatus formed by spokes radiating from the center, on the under side of which, near the end, are attached wheels with proper contrivances so that different pressures can be exerted by springs corresponding to certain weights. These wheels are staggered on the spokes in such a way that in revolving they cover the roadway on which they run an even number of times. These wheels can be arranged with tires of any kind or of any width, with which it is desired to experiment, and the roadway paved with any material that is desired. By the arrangement of springs a given pressure can be obtained upon the wheels and the entire machine rotated at an even speed, so that with a certain number of revolutions the amount of wear on the pavement can be observed. This arrangement probably conforms more closely to actual wear on the street than any other that has yet been devised. Of course, the action of horses' hoofs cannot be determined. It would seem that, by a sufficient amount of experimenting with a machine of this character, a traffic unit could be evolved, to which different kinds of traffic could be referred, so that if the traffic on any street in any city could be said to be a certain number of traffic units per yard of roadway per day it would be known quite definitely what was meant. For instance, if it was discovered that the passing of wheels under a given load with 2-in tires, at a certain speed and with a certain weight per inch of tire, would wear a standard pavement a certain amount, that amount of traffic could be taken as 100 traffic units. Then the amount of wear with different loads, at different speeds

and with different tires, necessary to produce the same amount of wear could be referred to the same standard and its value in traffic units be determined by reference to the original standard. But even if this could be determined positively there would still be the difficulty of determining the exact amount of traffic on any street, but with experienced observers the results would be fairly accurate. It would seem that before traffic conditions can be figured accurately and scientifically some such scheme as the foregoing must be used.

Number of Vehicles on European City Streets. A knowledge of the number of vehicles using streets in different cities is of value. It is stated in the report of the Chief Engineer of Paris that on the Rue de Rivoli 42 035 vehicles passed in 24 hr. The following statement shows the daily traffic on some of the principal streets of foreign cities: Paris, Rue de Rivoli, 42 035, Avenue de l'Opera, 29 500, Rue Croix des Petit Champs, 20 480, Rue St. Honoré, 19 672; London, King William St., 26 [illegible]; Gracechurch St., 15 585, Queen Victoria St., 16 531, Cheapside, 15 206; Sydney, Australia, George St., 11 960.

Number of Vehicles on City Streets in the United States. In 1885 a series of observations were made under the direction of Gen. F. V. Greene to determine the amount of traffic in several American cities. The figures represent the number of vehicles of all kinds passing between 7 A.M. and 7 P.M.: Broadway, New York City, [illegible]; Broad St., Philadelphia, 6081; Devonshire St., Boston, 5362; Douglass St., Omaha, 4752; 15th St., opposite Treasury, Washington, D. C., 4520; Clark St., Chicago, 4389. In 1914 observations in the Borough of Brooklyn, New York City, showed the greatest number of vehicles in 8 hr to be 2815, on Flushing Ave. The traffic on this street, however, is made up of heavy units, as it is a street where there is a great deal of trucking. Observations taken in the Borough of Manhattan, New York, in 1914, show that on Fifth Ave., between 33rd and 34th Sts., 7520 vehicles passed between 8 A.M. and 6 P.M., and between 41st and 42nd Sts., 6803 vehicles. It might be of interest to know that only 15% of this total number of vehicles was horse-drawn between 33rd and 34th Sts., and 16% between 41st and 42nd Sts.

It may seem strange that the traffic in New York should be so much less in amount than that of Paris or London, but it must be remembered that the New York City figures are given only between 8 A.M. and 6 P.M. If these figures were continued on Broadway, for instance, from 6 P.M. to 12 midnight, they would undoubtedly be very much increased, if not doubled, as the automobile traffic between 42nd and 49th Sts. is without doubt greater during that time than at any other time of the day.

Requirements of Pavements. After a highway official ascertains the requirements of a highway, in order to fulfill those requirements fully, the properties of the different materials to be used in paving must be understood thoroly; and after that is known, and when it is practicable from a scientific standpoint, to determine the proper material, it will be found even then that common sense and good judgment must be used to a great extent, as many conditions must be taken into consideration. It will be found also that the wishes of the people doing business or living on the highway will not always coincide with the wishes of travel on the roadway, whether it be heavy business traffic, or light automobile traffic. The property owner wishes a quiet, smooth pavement, and one that is pleasing in appearance; the automobile owner wishes one that is smooth, and the truckman, one that will be durable, present light resistance to drawing a load, and give a good foothold for his horses, with no regard for noise; so that all the different property interests must be taken into consideration in addition to the scientific requirements and needs of the street. But the highway official must make a study of the different characteristics of the paving materials in order to have an intelligent idea as to how they should be used. The official, who decides on the material after the most careful investigation, will often find that the decision is displeasing to many people. This often must be the case, as the wishes of the users of a street many times conflict with the wishes of the people who do business on a street.

The users of a street desire a pavement that is most conducive to ease of trucking, and, if that be satisfactory, care little for the noise or other inconvenience, while the people who do business on a street, or occupy residences thereon, wish a quiet pavement and are not so much interested in its adaptability to traffic. The decision must be made after taking all things into consideration and adhered to, altho it will not always prove satisfactory to all. The appropriation is generally inadequate for the work, and careful study is necessary to bring about the best results. An eminent authority has said that if one has but 5 min in which to perform a difficult task, 3 min should be consumed in ascertaining how to do it.

3. Characteristics of an Ideal Road or Pavement

While no road or pavement that has ever been laid is perfect, in considering the subject it is necessary to take a perfect road or pavement as a standard. Such a road or pavement should be cheap, durable, easily cleaned, present light resistance to traffic, be not slippery, be easily maintained, be favorable to travel, and sanitary. Admitting that a perfect road or pavement should have these properties, it must be understood that they are not all of the same importance; but by discussing these different properties, and assuming that a perfect road or pavement has a value of 100, it will be possible to assign a percentage value to each one of these properties, and then, by referring these values to the different kinds of paving material, determine a percentage value for each type.

Cheapness. It may be said that cheapness is not a physical characteristic of any material. This is undoubtedly true. It must be admitted that it is an important factor. No matter how desirable, or how economical ultimately, any material may be, its first cost is a question of importance in deciding upon its availability. If a property owner or a highway department cannot pay for it, the question is settled at once; there is no chance for argument. A recommendation is often rejected, when its wisdom is not questioned, simply on account of the cost. When the best cannot be taken this phase is developed: with the money available, how can the best results be obtained? A person presenting a new plan or a new material will first be asked as to its cost, and, if it be expensive, it will be a hard task to have it receive a fair trial, except at the expense of the party commercially interested. Cheapness depends to a great extent upon locality. Thus a cheap material in one locality might not be a cheap material in another. For instance, paving brick is manufactured to a great extent in the Central West and can be furnished to nearby cities at a reasonable price, while the same material in New York or New England might cost so much, on account of the freight rates, as to be prohibitive. At the same time granite blocks, which can be cheaply supplied to all cities on the coast, would be expensive in the interior cities. Asphalt, on the other hand, forming so small a proportion of the weight of the entire pavement, is not affected to so great an extent by cost of transportation. So that, while cheapness as a property may have a certain value, the different materials will vary greatly in this respect. Cheapness, therefore, has been given a value of 15.

Durability. This is also an economic property. Upon this depends ultimate cost, and in this connection must be considered to a certain extent first with cost. If a pavement be cheap, and pleasing even, it can never be a complete success if it has not durability. Americans expect any construction to care for itself largely; they are not given to economies in repairs. Durability is affected by so many varied conditions that it

is discussed with difficulty. Paving materials have a physical life as well as a traffic life; that is, stone and brick are not affected by the action of the atmosphere and will last in a roadway until they are worn out by the traffic. Asphalt and untreated wood, however, have a limited life, even without traffic; in fact, it is probable that the life of both of these materials in a pavement is increased by a certain amount of traffic. The influence of traffic is modified by five principal conditions, namely, width of roadway, character of road or pavement, presence or absence of street-car tracks, state of repairs, and how well the pavement is cleaned.

Width of Roadway. The distance between curbs or shoulders affects traffic, as it tends to scatter or congest it. The wider a roadway is, the more even will be its wear. If several lines of traffic can be maintained irregularly over the surface of the roadway, the wear will be more uniform and a better service received from the road or pavement. When vehicles are restricted to direct lines, the wheels move in practically the same place from day to day, and the result is a rough and uneven surface in a comparatively short space of time. Then, too, there is a certain part of the roadway adjacent to the curb or car track that cannot be efficiently used. This width is positive, and, in a narrow roadway, proportionately reduces the available roadway for traffic much more than in a wide roadway. If, for instance, this unavailable space is 2 ft on each side, on a 30-ft roadway there would be left 26 ft for traffic, while on a 60-ft roadway there would be 56 ft left for traffic; so that, while the actual roadway would be doubled, the available roadway for traffic would be more than doubled.

Character of the Road or Pavement. By this is meant, not the material that is used, but the detailed method adopted in constructing the roadway. Sheet-asphalt pavements, for instance, have been standardized, slight variations being made sometimes to meet special traffic conditions, but with stone, brick and wood it is different. While concrete as a rule is used for foundations for these different materials, it is not always so used. The joint filling varies according to the experience or the inclination of the particular engineer in charge. Wood of one variety is used in one locality and of a different kind in another, and while at present it is treated chemically in nearly all cities, the material used and the amount of the preservative are generally different. So that wood, stone, or brick, as referred to pavements, are somewhat indefinite unless it is known just how they have been used.

Presence or Absence of Street-Car Tracks. All foreign constructions in the surface of a roadway have a very material influence on its wear. Manhole heads are of iron, and must necessarily be of a different degree of hardness from the road or pavement, no matter what its character. As it is impossible to keep the surface of the roadway always level with the manhole head, when the wheel leaves the iron it pounds upon the roadway with greater severity, inducing greater wear than would occur if the surface were smooth and even. While manhole heads are objectionable, they are not as great a detriment to the pavement as the car tracks. It is recognised by all engineers that car tracks must exist in city streets, but it is also recognized that they cause extra wear of the pavement. This is not only because it is difficult to keep the tracks at the same level with the pavement, but because if the tracks are in fairly constant use, the traffic is concentrated on the sides of the streets and in practically regular lines. With a sheet pavement like asphalt the horses' shoes, especially in warm weather, often mark the pavement very materially. If the street is free

from car tracks the wheels of the different vehicles are likely to iron and smooth out the inequalities caused by the horses' shoes, which cannot often be done on car-track streets, because the traffic is restricted to distinct lines. In 1911 it cost 6.5 cents per sq yd to keep in repair the sheet-asphalt pavement on street-car streets in the Borough of Brooklyn, New York City, and 2.9 cents per sq yd on streets where there were no car tracks. In 1914 it cost 3.4 cents per sq yd on street-car streets, and 1.9 cents per sq yd on streets where there were no tracks. In a report of the Department of Public Works of Buffalo for 1910, it is stated that the presence of street-car tracks in streets reduces the life of the pavement about 2 years.

State of Repair. This is of vital importance in the maintenance of roadways. The old saying, " A stitch in time saves nine," can be applied with as much force to roads and pavements as to any other form of construction. If holes, depressions, ruts or any other defect in the surface are allowed to remain for any length of time, the material is displaced and consequently is worn abnormally. It is possible to permit a street to get into such condition that traffic will avoid it, so that it will not be worn extensively, but all streets should be kept in as nearly perfect condition as possible at all times, and in any discussion of this character the assumption is made that such is done. This fact impresses itself if the action of traffic upon stone blocks that have been relaid temporarily in a trench awaiting final reconstruction is observed. The unevenness of the surface and the looseness of the blocks allow the corners to be worn off and the blocks damaged very much more than if the pavement were smooth and even. It is very noticeable in any large city that the pavement in front of a park and large public buildings, where the surface is not disturbed for any subsurface work, is always more durable and in better condition than where it is regularly built up on both sides. No matter how well the pavement may be replaced temporarily, there is always an undue amount of wear upon the edges of the excavations. It often happens that in large cities in the construction of business blocks the basement excavation is carried out to the curb line, which always causes a settlement in the pavement proper; and when building material is stored on the street, the traffic is diverted to one side, causing an undue wear, especially if the pavement be sheet-asphalt. While it is difficult to figure upon the exact effect of the openings in pavements, as it depends so much upon the number of openings and the character of the traffic, it is probably true that if no openings of any kind were made in a pavement its life would be increased 15 to 20%.

Cleanliness. The effect of refuse on a roadway varies with its character. Any imperishable material is benefited by having a cushion of detritus upon it; it serves as a carpet to protect the road or pavement, which, when the cushion is heavy enough, becomes really the foundation. This fact will often explain why certain materials are much more durable in a small city than in a large one. A poor brick pavement, for instance, will often give good results in a small place, where the pavements are cleaned only at long intervals, when it would rapidly fail if kept clean under the same traffic. This, however, will not hold good with wood or sheet-asphalt pavements. Any street debris collects and retains moisture, which hastens the action of disintegration and decay in any perishable material. A case was cited where the contractor refused to repair a sheet-asphalt pavement, where the guarantee required that the pavement should be kept in repair from the effects of traffic, because the pavement was not kept normally clean, and for that reason it wore much more rapidly than it would normally,

and that the guarantee could not, therefore, be enforced. While this point was argued to a considerable extent, the court decided that the contract required repairs to be made when ordered by the City Engineer, and that the question of proper cleaning was not material.

All of the conditions referred to modify the action of traffic, and thus affect the durability of any material. Durability has been considered to have a value of 21.

Easiness of Cleaning. The experience of the larger cities, and in more recent years of all cities that have pavements, has demonstrated that it is not only feasible but extremely desirable to have pavements kept free from natural street refuse. In fact, it is generally accepted that it is not only desirable but absolutely necessary, and, while all cities recognized this, the degree of cleanliness must be governed by the amount of the appropriation. The appropriation for the Street Cleaning Dept., New York City, for 1915, was $7 646 186.74. The benefit of smooth pavements as related to street cleaning will be appreciated from a statement made by Waring (29), at a meeting of the Am. Soc. C. E., who said that if all the streets of New York, meaning at that time Manhattan and The Bronx, were paved with sheet-asphalt, where the grades would permit, and the street-car tracks constructed with grooved rails, the cost of sweeping the entire city would be reduced from $1 200 000 per annum to $700 000 per annum; that is, there would be a saving annually of $500 000 in New York, which then had a pavement mileage of 431, of which 95 miles only were paved with sheet-asphalt. While this statement was made in 1896, the principle is as good to-day as then, and is one of the very few statements that can be quoted definitely on this subject. A value of 15 is given to easiness of cleaning.

Resistance to Traffic. This is a very important item. One of the chief provinces of a road or pavement is to reduce resistance to traffic, and consequently any road or pavement that can bring it to a minimum is of special value. Any mechanical device that would reduce the friction of a machine 25 or 50% would be recognized at once as of great benefit. There is more than this difference in various roads and pavements, and this difference must be fully considered and carefully weighed before deciding on any particular material. If one horse can draw on one road or pavement a load that would require two horses on another, the truckman at once sees the importance of a proper selection. Of course, all highways are not heavy traffic streets, but the application in this respect will be taken up in detail later. Light resistance to traffic is valued at 15.

Non-Slipperiness. The slipperiness of a pavement depends upon its material, also upon its condition and how constructed. The efficiency of a draft horse varies with foothold. If that be good, the entire strength of the horse can be used to draw the load; while if there be constant danger of slipping and falling, very little will be accomplished. Instead of using all power to overcome the resistance of the load it is used only to the slipping point, and often a horse has difficulty in maintaining a foothold even if there is no load to draw. The condition of the weather and the climate modifies this. An illustration of this was shown in a case where observations were being taken on several sheet-asphalt paved streets in extreme winter weather. On the first day the hourly traffic was 225 tons between 11 and 12 o'clock, reaching 270 tons between 3 and 4 P. M. On the following day the traffic between 11 and 12 o'clock was 305 tons. About 2 P. M. snow began to fall, the mercury being about −18° C (0° F), making the pavement so slippery that the traffic was reduced to 40 tons between

3 and 4 P. M., and the street was soon practically deserted. The same results were obtained on all other streets where observations were being taken. Non-slipperiness is assigned a value of 7. In the light of the foregoing statement this value may seem small, but it must be remembered that these special conditions seldom arise, and, altho effective while they exist, do not have as much influence as a smaller force acting continually. For instance, if a street is used by a continuous traffic, without regard to weather, slipperiness is extremely important, but then only on the days when weather conditions materially affect the surface. If, on the other hand, the street is in such a locality that the traffic can be easily diverted on days when the pavement is especially slippery, the slippery quality is not of such great importance.

Ease of Maintenance. Maintenance is closely allied to first cost, and many engineers think that they should be taken together. To a certain extent this is true, but mainly when the question of ultimate economy is being considered. The cost of repairs should be ascertained as accurately as possible in advance. No material can be intelligently adopted without it. What often seems a wise and sound selection is ruled out simply by the cost of repairs. All works constructed by man require constant attention, and a pavement is no exception to the general rule; but that material which needs the least, and allows that to be done at the least expense as well as convenience to the public, is the best, other things being equal. By ease of maintenance is meant, not simply the cost, but whether the material is of such a character that repairs for pavement openings of whatever kind can be easily made and the original condition approximated. It is probably absolutely impossible to replace a pavement over a cut in general practice so that it will be as good as before it was opened, but it can be more nearly approached with some materials than with others; and as it must be recognized that openings will be made in pavements despite all precautions, the material that can be easily and properly replaced has a distinct advantage. This property is given a value of 10.

Favorableness to Travel. By this is meant the ease and comfort that are enjoyed in driving over a smooth pavement, and also the decrease in the wear and tear of vehicles as compared with one that is rough and uneven. It is difficult to estimate this exactly, but some approximations have been made.

French engineers make the general statement that 50% is saved in the wear and tear of vehicles by having smooth pavements. A London engineer in 1827 stated that good pavements in London, Westminster and Southwark would save £140 000 ($681 000) per annum in wear and tear of vehicles and horses. The area included in the above was 3818 acres. It must be remembered, however, that the streets of London at that time were in especially bad condition. In 1871, Deacon (14) stated that since the new Liverpool pavements had been constructed, without giving credit for the great reduction of wear and tear of horses and vehicles, there was a saving of £10 000 ($48 700) per year for every mile of the new pavements now laid on the dock line of the streets of Liverpool.

Smooth pavements are a luxury also. It is a pleasure to drive on some streets and positively painful on others. Wheeled vehicles are equipped with pneumatic tires to make the pleasure as great as possible, but much can be done to aid it in the pavement itself. With the introduction of the automobile and the motor-truck, with their rubber tires, and the possibility of their extension, this property of favorableness to travel is bound to receive more attention. At the present time, 1918, it is valued at 5.

Sanitariness. Another important requisite of a road or pavement is

that it should be sanitary. A great amount of decaying organic matter, house garbage, horse-droppings, and various kinds of filth must be deposited in the highways despite the utmost care. Altho the great introduction of automobiles, both for pleasure and business, has reduced this amount very materially, the matter still is of great importance. Any road or pavement that will allow any of this filth to collect in joints or soak down to the surface of the underlying soil or foundation, must be deleterious to the public health. Any material that will readily absorb moisture and give it forth in dry seasons must be considered as unsanitary. This fact is generally understood by municipal engineers, and it is recognized that all pavements should be practically waterproof. Therefore a road or pavement with a smooth surface impervious to water and not made up of organic matter subject to decay will be desirable from the standpoint of the sanitarian. Noise, too, is an important factor. A noisy material prevents sleep, rasps on the nerves of both the sick and the well. This fact is considered of great importance in large cities, where in selecting a material for repaving any street special care is taken that noiseless pavements be laid in front of churches, schools and hospitals. This is recognised to such an extent that noiseless pavements are laid on many streets despite the fact that it is understood that it is not proper from an economic standpoint. In the great improvement that has taken place in sanitary conditions in cities since 1890 the improvement in the character of pavements has been an important factor. Sanitariness is rated at 13.

4. History Cards and Report Forms

History Cards often supply the most valuable data that can be obtained in connection with the selection and design of highways. They correlate actual results of the use of methods and materials under known conditions Such results are of inestimable value in the preliminary investigations of other highways and the comparison of the relative suitability of the various types of roads and pavements for given local conditions.

History Cards Recommended for the Use of the N. Y. Highway Comm. (9). There are submitted herewith forms embodying outlines of the data which history cards should contain. "Form No. 1 should be considered as the main history form, printed upon 5 by 8 in white cardboard. Upon the back of this card the maintenance and repair record, shown on form No. 2, should be printed. A material record card, shown in form No. 3, printed upon light green cardboard; a traffic record card, shown by form No. 4, printed upon light pink card board; and a history of physical condition record, shown by form No. 5, printed upon light buff cardboard, should accompany each history card. Under ordinary conditions the four cards, when filled out, will constitute the complete history of a given highway.

"Material record form No. 3 should be of great assistance in correlating service results with the actual quality of the materials of construction; and while the card itself does not contain a complete record of tests, all of the information necessary to quickly secure such records is given. The last column headed Physical Characteristics would contain the results of some of the most important physical tests such as abrasion and absorption for brick, loss on abrasion and toughness for stone, penetration for asphalt, etc.

"Traffic record form No. 4 and the tally form are of course two distinct records, the former being a summary of a number of the latter.

"History of physical condition, form No. 5, should constitute a dated record which would cover such information as disintegration, nature and probable cause, displacement of surface, ruts, potholes, waves, etc; condition in summer, soft or otherwise; condition in winter or when wet, slippery or otherwise; nature of wear, condition adjacent to curbs, edgings, shoulders and rails; wear on curves and steep grades; and effect of various classes of traffic.

Form No. 1.—General Data and Original Construction.

Highway No............... Type...
Specifications, year............ Title, Type No. or Item No.......................
Name.................................. County..............................
Length........miles......feet........feet width....................sq yds.
Crown............ Max. grade .... Traffic....................
Population.. Total....................
Contract awarded.......................... Work started........................
Contract date completion.................... Contract completed...............
Contractor................................ Address...........................
Nature sub-grade.......................... Natural drainage....................

	Depth, Inches	Total Cost	Cost, Square Yard
Concrete foundation course..	....	....	....
Sub. bottom course........	....	....	....
Bottom course..........	....	....	....
Top or wearing course......	....	....	....
Other items...........	....	....	....
Grading cost...........	....	....	....
Drainage cost..........	....	....	....
Total pavement.......	....	....	....

Orig. cont. cost............ Eng'rs est........... State share..............
Supple'l cont. cost.......... Eng'rs est........... County share..............
Eng. & adv. chrgs.......... Eng'rs est........... Town / Village } share..............
Total highway cost......... Eng'rs est........... Total cost..................

NOTE.—This form should be printed on white cardboard. For reconstruction this form shall be printed on yellow cardboard and the heading changed to read GENERAL DATA AND.......................... RECONSTRUCTION. Blank space should be filled in with First, Second, Third, etc, as the case may be.

Form No. 2.—Maintenance and Repairs

Date	Age Highway	Character of Work and Remarks	Total Cost	Cost Square Yard
....	....	....	....	....
....	....	....	....	....
....	....	....	....	....

NOTE. This form should be printed on the back of form No. 1, both on white and yellow cardboard.

Form No. 3.—Materials: Original Construction, Reconstruction and Maintenance

Highway No.............

Year	Material	Geological or Trade Name	Specification Number	Name or Number of Item	Sample Number	Date	Cost	Results	Physical Characteristics
......	......	......	......	......	......	......	......	......	......
......	......	......	......	......	......	......	......	......	......
......	......	......	......	......	......	......	......	......	......

NOTE. This form should be printed on front and back of light green cardboard.

Form No. 4.—Traffic Record

Highway No..............

Date								
Station								
Weather								
Motor cycles								
Motor runabouts								
Touring cars, open or closed								
Motor-buses								
Motor-trucks, empty								
Motor-trucks, loaded								
Miscellaneous								
Total motors								
One-horse vehicles								
Two- or three-horse vehicles, empty								
Two- or three-horse vehicles, loaded								
Four- or more horse vehicles, empty								
Four- or more horse vehicles, loaded								
Miscellaneous								
Total horse drawn								
Grand total								
Class								

NOTE. This form should be printed on front and back of light pink cardboard.

Form No. 5.—History of Physical Condition of Highway

Highway No..............

Date	General Description

NOTE. This form should be printed on front and back of light buff cardboard.

Records of Cost Data are essential if an intelligent comparison is to be made of the relative value of different types of roads and pavements.

Lewis (21) states that "Cost records of highway work should indicate as clearly as possible the proportion of the expense chargeable to:

1. Permanent betterments, such as land purchases, grading, the improvement of lines and grades, masonry and steel bridges and culverts. This part of the work once done may be considered permanent or sufficiently durable to outlast more than a single generation.

2. Curbing, gutter pavement, fencing, guard rails, wooden bridges, concrete foundation, planting, etc, all of which may need periodical repairs, but will probably last 20 years at least.

3. The roadway surface, which will begin to deteriorate at once, and will need constant attention and periodical renewal.

"For each piece of work the records should include:

1. The character and first cost of the materials.

2. Cost of delivery on the work, with kind of transportation and distance hauled.

3. Cost of labor of all classes and the quality of same.
4. Cost of present value of plant and equipment, with allowance for depreciation due to the work under construction and not previously marked off.
5. All overhead charges, including engineering and inspection.
6. Cost of bonds, permits, etc.
7. All delays due to weather, failure to receive materials, strikes, or other causes.
8. A precise description of the methods employed and of the surface treatment of the road.
9. A statement as to the results obtained, the probable causes of failures or unsatisfactory work, and the means employed to correct or remedy them.
10. The manner in which the funds to pay for the work are raised, whether by cash appropriations, by the issue of bonds, with length of term and rate of interest, or by money advanced in anticipation of the collection of assessments for benefit."

Form of Record for Data Concerning the Use of Highway Materials, as recommended by the Spec. Com. Mat. Road Cons., Am. Soc. C. E., in its 1918 Rep. (6c). " The following forms of records are recommended for the use of Highway Engineers. They cover both bituminous and non-bituminous materials. Altho combined in a single table, it is believed that the data for different kinds of road surfaces can advantageously be placed on separate sheets or cards for convenient filing and reference."

General Information

State............................County..................Town or City.......
Road or street..........................Limits of improvement...............
Length of improvement, in feet...
Width of crust or pavement, in feet, average...............................
Area of crust or pavement, in square yards.................................
Kind of surface and foundation...
Percentage of grade, maximum percent.......Minimum percent.................
Amount of crown, maximum......, minimum...., Nature of subgrade............
Maximum and minimum air temperature during year............................
Hours of working day.....................Labor wage per hour...............
Contractor...
Dates of beginning and completion of improvement...........................
Class of highway or nature of traffic......................................

Traffic Census

For....hours, being the average of....observations taken between the hours of ....and........on........................
Location of point of observation...

	Commercial Vehicles		Weight *	Passenger Vehicles
	Empty	Loaded		
One-horse vehicles............				
Two- or three-horse vehicles........				
Four- or more horse vehicles........				
....				
Motor-cycles..................				
Motor-runabouts................				
Motor-touring cars, open or closed..				
Motor-buses				
Motor-trucks..................				

* Estimate, in pounds, of maximum load per inch of tire.

Construction and Cost Details

A. FOUNDATION. (1) Material; (2) thickness; (3) cost per square yard; (4) estimated life, in years.

B. WEARING COURSE. (1) Material; (2) thickness; (3) size of block or brick; (4) kind and amount of bituminous cement; (5) kind of joint; (6) proportions of aggregate; (7) cushion or binder course; (8) first cost per square yard; (9) life, in years; (10) average annual maintenance cost per square yard during life of wearing course.

C. TRAFFIC DATA. (1) Tons per year, 2000 lb.; (2) average tons per yard of width; (3) proportion of tonnage on metal tires; (4) proportion of C-3 on tires 2 in or less in width.

ITEMS OF COST FOR EACH SQUARE YARD. Foundation: materials; labor, superintendence; overhead, including interest on plant, depreciation, etc. Wearing Course: materials; labor; superintendence; overhead, including interest on plant, depreciation, etc.

DATA PER SQUARE YARD

A-3. First cost of foundation ....
A-5. Annual interest and sinking fund for foundation ....
A-6. Total annual cost of foundation ....
B-10. Annual maintenance cost of wearing course ....
B-11. Annual interest and sinking fund for wearing course ....
B-12. Total annual cost of wear ingcourse ....

YEARLY COST PER 1000 TONS OF TRAFFIC $= \dfrac{A\text{-}6 + B\text{-}12}{C\text{-}2} \cdot 1000 =$ ....

Non-Bituminous Materials

The following data or such parts as apply to a particular road or street could be incorporated on the sheet or card containing the data immediately preceding, or could be placed on a separate sheet or card containing the results of tests and analyses.

BROKEN STONE AND BROKEN SLAG. Name and origin; specific gravity; absorption of water per cubic foot; abrasion, percentage of loss; toughness; cementation; crushing strength per square inch; mechanical analysis; percentage of voids, loose and compacted.

GRAVEL. Location; specific gravity; abrasion, percentage of loss; cementation; mechanical analysis; percentage of voids, loose and compacted.

SAND. Location; specific gravity; mechanical analysis; percentage of voids, loose and compacted; tensile strength in cement briquettes, as compared with standard Ottawa sand.

MIXTURES OF SAND OR OTHER FINE HIGHWAY MATERIALS WITH BROKEN STONE, BROKEN SLAG, OR GRAVEL. Specific gravity; mechanical analysis; percentage of voids, loose and compacted.

PAVING BRICK. Composition; name of manufacturer; rattler test, percentage of loss.

STONE BLOCK. Name and origin; specific gravity; absorption of water per cubic foot; abrasion, percentage of loss; toughness; hardness; crushing strength per square inch.

WOOD BLOCK. Character of wood; weight of blocks; soundness; rings per radial inch; quantity of preservative; absorption of water after treatment. Character of preservative: Specific gravity at 25° C (77° F); specific gravity at 38° C (100° F); solubility in benzol or chloroform; water content. Distillation of preservative: Up to 170° C; 170° to 200° C; 200° to 210° C; 210° to 235° C; 235 ° to 270° C; 270° to 300° C; 300° to 315° C; 315° to 355° C.

PORTLAND CEMENT. Loss on ignition, percentage; insoluble residue, percentage; specific gravity, retained on 200-mesh sieve, percentage; retained on 100-mesh sieve, percentage; steam test; initial set, time in minutes; final set, time in minutes; tensile strength, neat, 24 hr; tensile strength, neat, 7 days; tensile strength, 1:3 Ottawa sand, 7 days; tensile strength, 1:3 Ottawa sand, 28 days; compressive strength, per square inch; constancy of volume.

Mechanical Analysis	Percentages by Weight		
Passing 200-mesh sieve	......	......	......
Passing 100-mesh sieve, retained on 200-mesh sieve	......	......	......
Passing 80-mesh sieve, retained on 100-mesh sieve	......	......	......
Passing 50-mesh sieve, retained on 80-mesh sieve	......	......	......
Passing 40-mesh sieve, retained on 50-mesh sieve	......	......	......
Passing 30-mesh sieve, retained on 40-mesh sieve	......	......	......
Passing 20-mesh sieve, retained on 30-mesh sieve	......	......	......
Passing 10-mesh sieve, retained on 20-mesh sieve	......	......	......
Passing ¼-in screen retained on 10-mesh sieve	......	......	......
Passing ½-in screen retained on ¼-in screen	......	......	......
Passing ¾-in screen retained on ½-in screen	......	......	......
Passing 1 -in screen retained on ¾-in screen	......	......	......
Passing 1¼-in screen retained on 1 -in screen	......	......	......
Passing 1½-in screen retained on 1¼-in screen	......	......	......
Passing 2 -in screen retained on 1½-in screen	......	......	......
Passing 2½-in screen retained on 2 -in screen	......	......	......
Passing 3 -in screen retained on 2½-in screen	......	......	......
Passing 3½-in screen retained on 3 -in screen	......	......	......
	......	......	......

Bituminous Materials

The following forms are given as illustrations of those to be used for recording the properties of bituminous materials.

Asphalt Cements for bituminous Macadam, Bituminous Concrete, Asphalt Block and Sheet-Asphalt Pavements and Fillers for Brick and Stone Block Pavements. Trade name; manufacturer; general characteristics; specific gravity at 25° C (77° F); flash point. Solubility in CS_2, carbon disulphide: Organic matter insoluble; inorganic matter insoluble. Solubility of bitumen in CCl_4, carbon tetrachloride; solubility of bitumen in petroleum naphtha; penetration 4° C (39° F), 200 g, 1 min; penetration 25° C (77° F) 100 g, 5 sec; penetration 46° C (115° F), 50 g, 5 sec; float test; melting point by ring and ball method; ductility at 4° C (39° F); ductility at 25° C (77° F); fixed carbon content; paraffine content. Loss on evaporation at 163° C (325° F), 5 hr; penetration of residue 4° C (39° F), 200 g, 1 min; penetration of residue 25° C (77° F), 100 g, 5 sec; penetration of residue 46° C (115° F), 50 g, 5 sec; melting point of residue by ring and ball method; float test on residue; ductility of residue at 4° C (39° F); ductility of residue at 25° C (77° F).

Tar Cements for Bituminous Macadam and Bituminous Concrete Pavements and Fillers for Brick and Stone Block Pavements. Trade name; manufacturer; general characteristics; water; specific gravity at 25° C (77° F); flash point; solubility in CS_2, carbon disulphide; specific viscosity, Engler; melting point, by cube method; float test. Distillation by weight and by volume: Up to 110° C; 110° to 170° C; 170° to 235° C; 235° to 270° C; 270° to 300° C; specific gravity of total distillate at 25° C (77° F); melting point of residue, by cube method; float test on residue.

PROPERTIES OF PAVEMENTS

5. First Cost of Pavements

The pavements that will be considered, for illustrative purposes, are the regular oblong granite blocks, with bituminous and gravel, and cement-grouted joints; sheet-asphalt, with a wearing surface 2 in thick and binder 1 in thick; vitrified brick, the joints being filled with bituminous material or Portland cement grout; treated wood blocks, and Bitulithic, all laid on 6 in of Portland cement-concrete. The discussion is too general to take up in detail the different methods of laying the various kinds of pavement, altho of course in actual wear that would be very material.

The first cost of pavements will vary very materially in every locality and a different apportionment must accordingly be made for every change in price. The cost will vary, too, in addition to this, in accordance with

general conditions as well as competition or variation in price of the materials. The following figures are based upon what would be considered average prices per sq yd in New York City under ordinary conditions, altho they are somewhat higher than bids received in 1915: Granite block, $3.50; wood block, $3.50; sheet-asphalt, $2.00; brick, $2.25; Bitulithic, $2.35. Note: The price of the brick and the Bitulithic is estimated, as neither of these materials is laid to any extent in New York City.

Bituminous Pavements. Blanchard (8), gives the average cost of constructing a bituminous surface, using ½ gal per sq yd with either an asphaltic or a tar product, or a combination of the two, as 7 cents per sq yd, but that the cost of bituminous concrete pavements varies with the kind and quantity of bituminous material used, the character of the aggregate, and the type of construction employed. As an illustration of that he gives the cost of one type, which he describes in detail, as being from 25 to 35 cents in excess of water-bound macadam, and for two other types, with mineral aggregates of broken stone and sand, with or without other fine material, at $1 to $2.25 per sq yd, including the foundation course and light grading.

Crosby (8) states that the cost of building a bituminous macadam pavement, using 1¼ to 2¼ gal of bituminous material per sq yd, averages between 15 and 25 cents per sq yd over and above the cost of water-bound macadam under the same conditions.

There are a great many different kinds of bituminous pavements and the costs vary very materially. On a large contract for a bituminous concrete pavement constructed around the Ashokan Reservoir in New York State, where the road crust was formed of stone passing over a ½ in screen and thru a 1½ in screen, the stone being properly heated, and mixed with an asphaltic cement so that the resulting mixture contained between 5 and 7½% of bitumen, the surface after rolling being covered with a seal coat of hot asphaltic cement at the rate of a little less than 1 gal per sq yd, the cost was $1.01 per sq yd for a surface 2 in thick.

In the Borough of Queens, New York City, 100 miles of roads were surfaced with a bituminous concrete pavement, known in that locality as the Topeka mixture, the mineral aggregate ranging from less than 10% passing a 2-mesh sieve to from 5 to 11% passing a 200-mesh sieve, the finished pavement containing between 7 and 11% of bitumen, and costing from $1 to $1.25 per sq yd for 2 in of thickness. In 1914 roads of this character were laid in New York State by the State Highway Department at a cost of 85 to 95 cents per sq yd.

In New York State in 1914 bituminous macadam pavements 3 in thick constructed by the penetration method were laid at a cost of 50 to 60 cents per sq yd. Breed (10) states that in 1916 the average cost of water-bound macadam, on 434 highways, was $0.648 per sq yd; and of bituminous macadam, on 134 highways, was $0.871.

In Massachusetts, in 1914, using 2¼ gal per sq yd of Bermudez asphalt, the cost of bituminous macadam was from 65 to 80 cents per sq yd for a 2-in thickness. A road crust composed of oil asphalt and gravel, using 18 gal of asphalt to 1 cu yd of gravel and spreading so as to have a thickness of 2 in after rolling, was laid at a cost of 30 to 35 cents per sq yd; while with oil asphalt and sand, mixed and spread to a depth of 4 in after rolling, the cost was from 54 to 60 cents per sq yd. Using the penetration method, with tar instead of asphalt, and with 2¼ gal per sq yd of surface, 2 in thick after rolling, the cost was 45 to 65 cents per sq yd. In explanation of these variations of cost it can be said that gravel cost 80 cents per cu yd and trap rock $2.50 per ton.

Cement-Concrete Pavements. When the traffic of a road is so heavy that a bituminous concrete crust does not seem to be proper, recourse is had to more durable materials, and asphalt blocks, brick, and even granite block are used. It sometimes occurs too that, even if under ordinary conditions a bituminous concrete would be suitable, the local conditions are such that Portland cement-concrete or brick will be more economical in the long run. Portland cement-concrete has come into very general use since 1910, and is now used to a large extent in all states where good roads are being built. While their first cost is somewhat greater than for some types of bituminous road crusts, their durability makes cement-concrete pavements an economical material, when ultimate cost is considered. The first cost varies a good deal in different localities.

In Wayne County, Mich., where cement-concrete pavements first received general recognition and where they are being used almost entirely in road construction, all materials have to be brought from out of the county, even the water with which the concrete is mixed is piped long distances, so that the cost is necessarily great. These roads cost on an average about $1.35 per sq yd. On Michigan Ave., where the concrete was laid an average depth of 7 in and mixed in the proportion of 1 part of cement to 1½ parts of sand and 3 parts of gravel, the cost was $1.47 per sq yd.

In Massachusetts cement-concrete roads laid in 1914, with an average depth of 7¼ in, cost from $1.40 to $1.55 per sq yd; while in New York State, in the same year, with a mixture of 1 part of cement to 1½ parts of sand and 3 parts of broken stone, the cost was $1 per sq yd, for a depth of 6 in. Breed (10) states that, in 1916, the average cost, on 20 highways, was $1.121 per sq yd.

Brick Pavements. Vitrified brick has been used extensively in the Central West, particularly in localities where it is manufactured and especially in the vicinity of Cleveland. Brick roads vary in cost according to the transportation charges, as the brick is exceedingly heavy, and freight charges make a material charge against the cost of the road. In the vicinity of Cleveland the cost has been from $1 to $1.10 per sq yd, not including foundation.

Conclusion. Assigning, then, values to these different materials inversely as the cost, granite block has a value of 2, wood block 4, sheet-asphalt 4, brick 3, and Bitulithic 3. These values are local and must be changed for each city.

6. Cost of Maintenance of Pavements

The cost of repairs to pavements varies greatly in different cities. It is governed principally by the character of the material, nature and amount of traffic, and the condition in which the streets are kept. In America very few satisfactory records are available on this subject. Few cities keep their accounts in such a manner that it is possible to tell how much money has been spent on different pavements. Then, too, officials of different cities have different standards of repair. One city will not tolerate what is considered good in another. Then some cities have only a certain amount of money and the figures given would show that sum rather than what was necessary to keep the pavements in repair.

Stone Block Pavements. ENGLAND. Brodie, City Engineer of Liverpool, estimates that 6-in stone blocks will sustain a traffic of 9 482 000 tons per yard of width before being worn out, and that the life of the pavement will be governed by the amount of traffic each year.

The stone block pavements of PARIS in 1911 cost 13 cents per sq yd.

Wood Block Pavements. Wood (4) gives the cost of repairs to wood block pavement as 2 cents per sq yd. This, however, is very much less than the cost in London proper, where it is given as 20 cents per sq yd on the average, altho some streets cost as high as 43 cents.

In LEIPSIC, GERMANY, the cost of keeping the wood block pavements in repair for 15 years after a guarantee period of 5 years was 5 cents per sq yd for hard wood block and 10 cents for soft wood blocks.

In PARIS, in 1911, the repairs to wood block pavements cost 26 cents per sq yd.

In VIENNA the cost of repairs to soft wood block pavements is given as 11 cents per sq yd.

UNITED STATES. In America, treated wood block pavements have not been laid long enough to get information as to the cost of repairs, but in 1912, from reports of the principal cities using wood blocks to any great extent in this country, it was found that at that time almost nothing had been expended for repairs due to actual wear and tear of pavement. For instance, the first creosoted wood block pavement, on Tremont St., Boston, had been in use, 1912, 12 years and had cost nothing for repairs, and it was stated by the engineer of the Boston pavements that the same was true of 14 000 sq yd of other wood block pavement laid about the same time. Pavements

laid in Brooklyn, N. Y., the oldest of which at that time had been in use 10 years, had cost on an average 0.05 cent per sq yd per year, altho it was stated by the engineer in charge that practically all of these repairs were due to causes other than wear and tear. In Brooklyn in 1914 the cost of repairs due to wear and tear only on 67 169 sq yd of wood block pavement was 0.7 cent per sq yd. In the Borough of Manhattan, New York City, there were three streets in 1912 that had been out of guarantee 3 years, having been kept in repair 5 years without cost to the city. One of these streets was of heavy, one of medium, and one of light traffic. The heavy traffic street had cost 7 cents per sq yd per year, and the average of all had been 6 cents per sq yd per year; but the cost of repairs due to wear and tear was on the heavy traffic street only, which is a wholesale street in the business section. Minneapolis, Minn., reported that on 1 000 000 sq yd of wood block pavements, all laid by the city and the first in 1902, the greater part of the material being Norway pine and tamarack, the cost in 1911 was less than 0.1 cent per sq yd. In St. Louis, in 1909, repairs to 50 000 sq yd of wood block pavement, laid in 1903, cost $2.10, and in 1911 the same 50 000 sq yd cost less than 0.2 cent per sq yd, so that the total cost of repairing the 50 000 sq yd of wood block pavement the first 9 years they were laid was 0.2 cent per sq yd. These pavements were all on light traffic streets.

Rock Asphalt Pavements. LONDON. The average cost of keeping in repair the rock asphalt pavements of London is 30 cents per sq yd per year, but one contract was made for repairing the rock asphalt pavement on Cheapside for 15 years, after it had been laid 2 years, at a price of 56 cents per sq yd per year.

In GLASGOW, Scotland, the cost of repairing rock asphalt pavements ranges from 8 to 20 cents per sq yd per year.

In PARIS in 1911, the cost of repairing rock asphalt pavements was 19.5 cents per sq yd.

Sheet-Asphalt Pavements. UNITED STATES. In Brooklyn, N. Y., in 1914, the cost on 5 875 000 sq yd was 2 cents per sq yd, but 0.4 cent of this was due to causes other than wear and tear. On railroad streets the cost was 3.4 cents and on streets, where there were no tracks, 1.9 cents per sq yd. In Buffalo, the cost of repairs in 1913 for sheet-asphalt was 3.17 cents per sq yd, but in a series of years the cost had been 3.78 cents for 43 000 000 sq yd.

Bituminous Macadam and Bituminous Concrete Pavements. In Massachusetts in 1914 the cost of repairs to 450 000 sq yd of bituminous macadam, heavy hot oil being used in the construction, the work having been done between 1911 and 1914, was $0.0119 per sq yd. The lowest cost on any one of these roads was $0.0043 per sq yd, on a road where the traffic consisted of about 200 automobiles and 75 vehicles with steel tires per day. The highest cost was $0.0234 per sq yd, on a road where the average traffic was about the same as on the above, but the material used was not supposed to be of so good a quality. On the same kind of a road, but where asphalt was used instead of oil, the cost on 80 000 sq yd was $0.0044 per sq yd. The highest cost on these roads was $0.0233 per sq yd, on a road which had been down but 1 year and where the average daily traffic consisted of 350 automobiles and 90 vehicles with steel tires. On the same type of road as the above, but where tar was used and where the work had been completed 2 years, the cost on 42 000 sq yd was $0.0064 per sq yd. On a bituminous gravel concrete road crust, where asphalt was used, the cost on 20 000 sq yd built in 1913 was $0.0098 per sq yd. On a tar concrete road crust constructed in 1910 the yearly cost had been $0.0049 per sq yd, including a seal coat of tar oil applied after the pavement had been down 2 years.

Brick and Cement-Concrete Pavements. It is extremely difficult to obtain much data regarding repairs to brick and concrete pavements. See Sects. 20 and 21. Maintenance costs per square yard on twelve different brick pavements in New York State has varied from $0.000 to $0.052; only one, however, cost nothing. The lowest cost of any where a figure is given is $0.0014. The average, not figuring yardage, was $0.0158. These roads have been in use from 2½ to 6 years.

On 13 concrete pavements that had been laid from 1 to 2 years, and surfaced with a preparation of tar, the cost ranged from $0.000 to $0.0691 per sq yd. On one pavement, however, that had been laid 2 years and had received a surface treatment of hot oil, the cost of repairs was $0.0544 per sq yd. The average for the 13 roads was $0.0252.

On a concrete pavement in Wayne County, Mich., ½ mile long, 9 ft wide, lead-

ing southerly from the town of Wayne, the cost of repairs in 5 years was but $26, and the road in 1914 was in good condition. The Chairman of the Board of Road Commissioners of that county states that it is expected that their pavements will cost on an average not more than $30 per mile per year for repairs.

Comparison of Maintenance Costs. Table II shows the cost of repairs to different kinds of pavements and road crusts in the City of Liverpool as worked out by Brodie, the cost being, as will be seen, not only per yard of surface, but also in tons of traffic per mile. These figures are valuable and probably the only ones of the kind that are available.

Table II

Pavement	Tons per Yard Width per Annum	Life years	Life Tonnage per Yard Width	Cost per Square Yard of Surface	Annual Cost Including Proportion of Capital and Maintenance per Square Yard	Ton Miles per Yd Width per Penny	Cost in Pence per Traffic per Mile (cent)
6-in Sets..........	524 000	18	9 432 000	10/—($2.43)	$8\frac{3}{4}$d ($0.18)	34.0	.029 (0.06)
4-in Sets..........	150 000	50 Est	7 500 000	7/6d($1.83)	$3\frac{1}{2}$d ($0.07)	24.0	.040 (0.08)
Hardwood.........	162 000	17	2 754 000	13/6d($3.29)	$12\frac{1}{2}$d ($0.25)	7.4	.136 (0.27)
Softwood..........	204 000	18	3 672 000	8/6d($2.07)	$7\frac{1}{2}$d ($0.15)	15.5	.064 (0.13)
4-in Pitch macadam	120 000	11	1 320 000	3/—($0.73)	$3\frac{1}{3}$d ($0.07)	20.6	.048 (0.10)
7-in Water-bound macadam.......	120 000	1	120 000		9d ($0.18)	7.6	.132 (0.27)
7-in Water-bound macadam, tar sprayed.........	120 000	2	240 000	1/—($0.24)	6d ($0.12)	11.4	.090 (0.18)

Note. Tonnages on Roads Board basis, except that exceptionally heavy traffic is based on estimated total actual weights.

Conclusion. The values assigned, therefore, for maintenance, are: Granite block 10, wood block 8, sheet-asphalt 6, brick 6, and Bitulithic 6.

7. Annual Cost of Pavements

An engineer who has charge of the construction, maintenance and renewal of a large amount of pavement will be governed more by ultimate economy than first cost. He must take into consideration, too, the interruption to travel by too frequent repairs. A material that might be figured out as economical, even if short-lived, by reason of its cheapness both of first cost and renewal, might require so much attention as to be an actual nuisance.

Annual Cost Formula. Taking the costs and lives of the different pavements as stated in Sects. 5, 6 and 8, the actual annual expense of each for a period as near 50 years as will be convenient for each material can be easily maintained and compared by the formula:

$$A + CI + \frac{R}{N} = \text{ANNUAL EXPENSE},$$

in which A represents the sinking fund to be paid each year to equal C at the end of N years; C, the first cost per square yard; I, the rate of interest; R, the estimated total cost of repairs if distributed over the entire life of the pavement; and N, the life in years of the proposed pavement.

For Granite Block Pavement: $C = \$3.50$; $I = 0.04$; $R = 2.00$; $A = 0.084$; $N =$ 25 years.

Substituting in the equation, $\$0.084 + 0.14 + \frac{2.00}{25} = \$0.304$ FOR FIRST PERIOD.

For the SECOND PERIOD, assuming the value of the concrete to be \$0.70 per sq yd, making the cost of relaying \$2.80 per sq yd, the annual expense is found as before to be \$0.2512, or for 50 years an average of \$0.2776.

For Wood Block Pavement: $C = \$3.50$; $I = 0.04$; $R = 1.00$; $A = 0.1176$; $N =$ 20 years.

Substituting, $\$0.1176 + 0.14 + \frac{1.00}{20} = \$0.3076$ FOR FIRST PERIOD; for SECOND PERIOD \$0.24604, and for 50 years an average of \$0.2706.

For Sheet-Asphalt Pavement: $C = \$2.00$; $I = 0.04$; $R = 0.72$; $A = 0.0714$; $N = 18$ years.

Substituting, $\$0.078 + 0.08 + \frac{72}{18} = \$0.198$ FOR FIRST PERIOD.

For any SUBSEQUENT PERIOD, assuming the cost of repaving to be \$1.25 per sq yd, the expense will be \$0.13875 per sq yd, and for 54 years an average of \$0.1585.

For Brick Pavement: $C = \$2.25$; $I = 0.04$; $R = 0.60$; $A = 0.1123$; $N = 15$ years.

Substituting, $\$0.1123 + 0.09 + 0.04 = \$0.2423$ FOR FIRST PERIOD.

For any SUBSEQUENT PERIOD, assuming cost of repaving to be \$1.55 per sq yd, the annual expense will be \$0.1793, or an average for 45 years of \$0.20 per year.

For Bitulithic Pavement: $C = \$2.35$; $I = 0.04$; $R = 0.72$; $A = 0.09165$; $N =$ 18 years.

Substituting, $\$0.09165 + 0.094 + 0.04 = \$0.22565$ FOR FIRST PERIOD.

For any SUBSEQUENT PERIOD, the cost will be \$0.17035, or an average of \$0.19 for 54 years.

Table III shows the above results condensed.

Table III

Material	First Cost per Square Yard	Expense per Sq Yd for First Period	Expense per Sq Yd for 50 Years
Granite block	\$3.50	\$0.3040	\$0.2726
Wood block	3.50	0.3076	0.2706
Sheet-asphalt	2.00	0.1980	0.1585*
Brick	2.25	0.2423	0.2000†
Bitulithic	2.35	0.2257	0.1900*

*54 years. †45 years.

Conclusion. These estimates give to granite block a value of 21, creosoted wood block 16, brick 12, sheet-asphalt 15, and Bitulithic 15 which are, of course, the same as given for DURABILITY, see Art. 8.

8. Durability of Pavements

The life of these pavements varies greatly according to conditions, so that any conclusion must be extremely general. For instance, a granite block pavement could be laid upon a residential street where the traffic was light and where it would last almost indefinitely. On the other hand, sheet-asphalt pavement could be laid on a street where the traffic was heavy and where its life would be measured by months almost rather than by years. It is stated by the engineer in charge of the pavements of Paris that on

certain streets rock asphalt pavements would not last more than 2 years while on others it would last 13 or 14 years. In considering the durability of different kinds of paving material as a whole it must be assumed that all of the streets of the city are paved with such material as is particularly adapted to the needs of each street, and that a heavy traffic street is paved with a material suitable for heavy traffic, and a light traffic street with a material that is inexpensive but is sufficient for the needs of the street. There are two ends to all pavements, a physical and an economic end. The former comes when the material is so worn out that it cannot be repaired and must be relaid; the latter when the cost of repairs is so great that it will be economy in the end to relay at once. The former test will generally be applied to stone, block, brick, or wood block pavements, and the latter to sheet-asphalt.

When a pavement is made of moderately sized parts of practically the same character, the wear on the parts is about the same over the greater part of the surface, and to repair it requires taking up the old material and replacing it with new rather than adding to the material itself on the street. The necessity of these repairs, and their extent, can generally be determined by an inspection, but when a pavement is made up of parts so small that they must be consolidated into a continuous whole it is different. Sheet pavements, like sheet-asphalt and Bitulithic, wear away by degrees and can be added to in whatever quantity it may be desired and their physical life prolonged indefinitely.

The Economic Test to Ascertain When Repairs Must be Stopped and a New Pavement Laid is as follows: Assume a street to be paved and to have arrived at such a condition that the expense of keeping it in repair is so great that the question arises, shall it be repaved or repairs continued? This question can be settled by the following formula discussed in Art. 7: $A + CI + \frac{R}{N}$ = ANNUAL EXPENSE OF NEW PAVEMENT. Take, for instance, a sheet-asphalt pavement, and let $N = 18$ years, $C = \$2$, $I = 4$, and $R = \$0.72$. Then A will equal \$0.0702 and the equation becomes $\$0.0702 + 0.08 + 0.04 = \$0.1902$, or if the street be repaved, it will cost annually \$0.19 till it is renewed. Consequently if the life of sheet-asphalt be correctly assumed at 18 years, it should not be repaved until the annual cost approaches \$0.19 per sq yd. Assuming the life to be 20 instead of 18 years and applying the formula as before, the annual cost will be reduced to \$0.1872 per sq yd. This is the scientific, the engineering, and the only true way of telling when a sheet-asphalt pavement should be relaid. The only element to modify this principle is the inconvenience to traffic and property owners on the street are put to while repairs are being made. The determination of this must be made in each case. But the principle of the formula is correct, and when cities have had a larger experience with sheet-asphalt pavements, and repair accounts are kept in a more intelligent way, there will be no difficulty in determining the variables.

Life of Pavements. The lives of different paving materials are governed by many different conditions as is illustrated by statements relative to how long the different pavements last in various cities.

Wood Block Pavements. ENGLAND. In London, a wood block pavement on the Strand, from Trafalgar Square to Charing Cross, was relaid in 1913 after it had been in use for 12 years. It is extremely doubtful if there is another street in the world that sustains as great a traffic as this street per yard of width, altho the tires of the vehicles are mostly of rubber and the wear and tear on the blocks are probably not as great as in other cities with less traffic but where the vehicles are steel-tired.

The life of another wood block pavement in London, on Gracechurch St., laid in 1913, was estimated by the assistant engineer of the city at 5 years, altho the contractor estimated it at 15 years. Wood (4) states that the Local Government Board of London has defined the life of soft wood block pavement at 7 years and of hard wood block at 10 years. Wood, however, states that if the actual life of the wood pavements in London had been considered, it would be found that there would be a very small amount that had been removed within 10 years, and that the average life would more probably be 12 to 15 years. But referring to actual wear he states that, from his observations, it has been found that the life of the best Swedish soft wood block, with a traffic of 100 tons per ft effective width of roadway per day, would be 0.061 in per annum. This is a positive and definite statement, and if a definite standard of traffic could be obtained, such a statement would be of greater and very positive value. Brodie, City Engineer of Liverpool, estimates that a soft wood block pavement will sustain a traffic of 3 672 000 tons per yd of width, and in that way he figures out the life of a pavement with its known traffic. These statements assume that the pavement will wear out rather than rot out, and if the amount of traffic comes during the physical life of the pavement, this may be true, but if it is distributed over a long term of years, it is questionable whether the assumption would hold good. In Sheffield, England, the average life of wood block pavement is about 13 years. It is said that on the Edgeware Road, Hampstead, England, where the traffic amounts to about 10 000 vehicles of all kinds in 12 hr, the actual wear on Jarrah paving blocks in 6 years amounted to only ¼ in. In Birmingham, England, the wear on the creosoted Swedish wood blocks in the business streets was said to be about ¼ in per annum.

Germany. In Berlin it is considered that the soft wood block pavement will last 12 years and the hard wood two or three times as long, altho the latter has not been laid to any great extent. In Breslau, on light traffic streets, wood block pavement is said to have lasted 25 years.

In Paris the life of the wood block pavement on the Champs Élysees is about 7 years, while the average over the entire city is 8 years. It must be remembered, however, that in Paris as a rule the heavy traffic streets are paved with wood blocks.

In Melbourne, Australia, it is said that red gum blocks, on fairly heavy traffic streets, in some instances lasted 24 years; and in South Melbourne, on a fairly heavy traffic street, with annual tar painting, the blocks had lasted 22 years and are still in use. On another street the blocks had been laid and in use 12 years with no apparent wear; the surface, however, had been tarred and sanded each year.

On Clinton Ave., Brooklyn, N. Y., a portion of a wood pavement was taken up after it had been in use 10 years, when the wear was found to be ¼ in. The traffic on this avenue is fairly heavy. The blocks were of long leaf yellow pine, treated with creosote and rosin.

Rock Asphalt Pavements. England. With a rock asphalt pavement, Wood estimates that a traffic of 100 tons per day per ft of width of pavement will wear the pavement 0.02 in per annum. Knowing the amount of traffic, the life of the pavement can readily be deduced. It is difficult to ascertain what is considered as the life of rock asphalt pavements in many foreign cities, as long maintenance contracts are made which cover more than simple repairs.

Sheet-Asphalt Pavements. United States. In America very little data has been kept which will give information of much value. In the report of the Bureau of Engineering of Buffalo for the year ending June 30, 1913, when over 1 000 000 sq yd of pavement had been replaced, the average age of the pavements relaid on streets where there were no car tracks was 18.29 years, and on streets with car tracks 16.85 years, and the average age of all was 17.48 years. In the City of Washington, D. C., the life of a sheet-asphalt pavement is taken as 20 years.

Stone Block Pavements. Europe. What has been said of sheet-asphalt is true as to the life of stone block pavements, altho in general the officials of different foreign cities give the average life of granite block pavements as follows: Glasgow, 50 years; Edinburgh, 30 years; Liverpool, 30 years; Paris, 30 years. These figures, even if correct, could not be applied to this country, as many residential streets in European cities are paved with stone, so that the life of the pavements is unduly long.

United States. From data collected from American cities the estimated life of granite block is taken at 25 years, creosoted wood block at 20 years, brick at 15 years, sheet-asphalt at 18 years, and Bitulithic at 18 years.

Table IV.—Annual Rates of Wear of Pavement Under Known Weights of Traffic (17)

	Kind of Pavement	Tons in 24 Hours	Road'y Width in Feet	Tons per Foot per 24 Hr.	Annual Wear in Inches	Rate of Wear per 100 Tons
Brooklyn Bridge..........	Granite	4172	8	522	0.2500	0.0490
Penn. R. R. Ferry at foot Cortland St. roadway....	Wood	2301	10	230	0.4870	0.2117
D. L. & W. Ry. Entrance at West 23rd St...........	Granite	6509	21	309	0.0202	0.0065
Atlantic Ave. Ferry at foot Whitehall St...........	Wood	1004	14	72	0.0501	0.0696
13th St. and 7th Ave. to Greenwich St...........	Sheet-asphalt	1650	30	55	0.1000	0.1820
14th St. from Ave. A to B...	Sheet-asphalt	2000	40	50	0.1470	0.2940
31st St. from Lexington to 3rd Ave...............	Rock asphalt	1500	30	50	0.1103	0.2206

Table V.—Consensus of Opinion of Canadian Engineers as to Durability (11a).

Pavement	Small Repairs	Extensive Repairs	Complete Recon-struction
	Years	Years	Years
Asphalt block......................	5 to 10	10 to 12	12 to 15
Asphalt concrete..................	4 to 6	6 to 8*	8 to 10*
Bitulithic..........................	5 to 8	10 to 15	15 to 20
Brick..............................	8 to 10	10 to 15	15 to 18
Cement-concrete..................	5 to 8	10 to 12	15 to 18*
Scoria block and stone...........	10 to 15	15 to 20	20 to 30
Sheet-asphalt.....................	4 to 8	10 to 15	15 to 18
Untreated wood block............	3 to 5	6 to 10	10 to 12
Treated wood block...............	8 to 10	12 to 15	15 to 18*

*These pavements have not attained an age in Canada sufficient to place the figures beyond conjecture.

Opinions of Canadian Engineers as to Nature of Deterioration (11a).

"Asphalt Block: Edge-wear forming holes and cobbles; worn pavement noisy and hard to keep clean; disintegration of bottom of blocks.

"Asphaltic Concrete: Wears in holes; susceptible to marking in hot, sunny weather.

"Bitulithic: Wears evenly, with a tendency to holes under heavier traffic; susceptible to surface marks in hot weather.

"Brick: Edge-wear and cobbling under heavy traffic; increased noise and unsanitariness as wear increases; when worn badly it slows down traffic.

"Sheet-Asphalt: Wears slowly into large holes or patches; heavy traffic causes ruts; cracks hasten deterioration.

"Wood Block: Rots rapidly if untreated, retarding traffic; treated block wears slowly and evenly; frost intrusion causes buckling.

"Stone and Scoria Block: Wears gradually into holes and cobbles; unsanitary when roughened.

"Cement-Concrete: Wear is slow and even if well placed; cracking and chipping develop otherwise."

Conclusions. In view of the data at hand, granite block is given a value of 21, wood block 16, brick 12, sheet-asphalt 15, and Bitulithic 15.

9. Easiness of Cleaning Pavements

Some figures have already been given showing the benefits of smooth pavements when they are to be cleaned. How necessary this is can be recognized from a statement made by a committee of the Society of Arts, London, in 1875, to the effect that at that time it was estimated that 1000 tons of horse manure was being dropped daily upon the streets of London. This had to be taken up and removed to avoid being incorporated into the human system thru the respiratory organs. These figures, too, would be revised as applied to 1918 on account of the use of the automobile both for pleasure and for business. Other refuse of all kinds, however, collects upon the streets, and the pavement that uniformly presents a hard, smooth and even surface is cleaned at much less expense than one that is rough and uneven.

In 1907 a Commission in New York City appointed by the Mayor to investigate the entire matter of street cleaning made a report from which the following quotation is taken.

"There is a very marked difference between the quantity of dust left upon the pavements of various kinds. Thus, if the average volume and weight collected from the sheet-asphalt pavement is called 100, the relative quantities from other kinds of pavements were:

	Volume	Weight
From sheet-asphalt	100	100
From asphalt block	180	182
From wood block *	332	145
From granite block	1081	912

*It should be said that the wood block pavement on which the examination was made is one of the oldest of its kind in the city, and its surface, being uneven, caught and held an unusual quantity of dust. Wood block pavement, when comparatively new, should compare favorably with asphalt block pavement in its freedom from dust retaining qualities.

"After careful consideration of all the facts available, the average relative cost of cleaning, equally well, the various kinds of pavement in use in the city under similar conditions of repair, is estimated as follows:

Sheet-asphalt pavement	100
Wood block pavement, new	105
Asphalt block pavement	115
Brick pavement	120
Wood block pavement, old	125
Medina block pavement	130
Granite block pavement	140
Belgian block pavement	150
Cobblestone pavement	3000

"On the assumption of 100 cleanings per year it may be shown that the annual cost of cleaning equally well a mile of each of the pavements named, over what it would be if sheet-asphalt were substituted, would be as follows:

Wood block pavement, new	$26.40
Asphalt block pavement, average condition	79.20
Brick pavement	105.60
Wood block pavement, old	132.60
Medina block pavement	158.40
Granite block pavement	211.20
Belgian block pavement	264.00
Cobblestone pavement	1584.00"

Philadelphia. Connell (12) gives the average cost of cleaning different kinds of pavement per 1000 sq yd in 1914 as follows: Granite block, $0.245; brick, $0.217; wood block, $0.217; sheet-asphalt. $0.187.

Conclusions. Taking all things into consideration, granite block is given a value of 10, wood block 14, sheet-asphalt 14, brick 15, and Bitulithic 14, always upon the assumption that the pavements are kept in good condition.

10. Resistance to Traffic on Pavements

Many experiments have been made to determine the force necessary to draw a given load over roads and pavements of different character. The most of them, however, were made many years ago, and, while doubtless correct at the time, were made upon pavements so entirely different in character and construction that they are not of much value at the present time. The tractive force, or the power necessary to move vehicles or loads, is measured generally in pounds per ton. In order to start a load that is stationary the power must be strong enough first to overcome the inertia of the load, then the rise in the grade, if it be up-grade, and then to overcome the friction of the moving load. The amount of power necessary to draw a load up a given grade can be figured theoretically, but so many different conditions must be taken into consideration that figures are not of much value. A great many experiments have been made at different times to ascertain the resistance to traffic on the different pavements, but the results have differed greatly. This can easily be understood when it is remembered how different the tractive force necessary to move a load on any pavement varies according to the condition of the pavement. The tractive force required to move a load on a sheet-asphalt pavement in perfect condition would vary according to the temperature of the pavement and the weight of the load. If it were so light as not to sink into the sheet-asphalt, no matter how soft it might be, there would be no particular difference, but in the summer time, under the heat of the sun, as a rule all sheet-asphalt pavements soften so that the tractive force is greatly increased. On a block pavement, whether stone, wood, or brick, the relative smoothness of the pavement has everything to do with the tractive force required to move a load. The general surface of a stone pavement can be smooth, but if the blocks themselves are bunchy, it will often be necessary to lift the wheel possibly ¼-in over a bunch, when on a dressed block the surface would be smooth and the tractive force required much less.

Experiments can be made, of course, under conditions that will give comparative results. At the Atlanta Exposition, in 1895, the U. S. Dept. Agr. made some experiments which resulted in giving a traction of 26 lb for poor sheet-asphalt, 54 lb for cobblestone, 42 lb for poor block pavement, 38 lb for the best macadam, and 320 lb for loose sand. Haupt (18), in 1889, gave results varying from 10 lb for iron trams to 400 lb for sand, the pavements being: sheet-asphalt 15, good Belgian block 33, stone block 80, French macadam 40, good cobble 133 to 66. Certain other experiments for sheet-asphalt under different conditions ranged from 15 to 26. The opinion among engineers is that the tractive force varies inversely as the diameter of the wheels. but some say inversely as the square root of the diameter. W. Hewitt, of England, says: "From experiments made with Eastren and Anderson's horse-dynamometer at the Royal Agricultural Show in 1874, a slightly greater ratio than inversely as the diameter was given, and hence inversely as the diameter is the more correct view of the two." See Sect. 4.

Test With Motor-Truck by Kennelly and Shurig (20). "By tractive resistance is meant the horizontal force necessary to apply to the truck in order to keep it at a constant speed in still air after deducting axle frictions and internal-mechanism losses. It is, therefore, the reactive force offered by the truck, assumed internally frictionless, in overcoming the road, tire and still-air resistances on a level surface. It may be expressed either in pounds weight per short ton of total moving mass, or in kilograms per metric ton, or in percent equivalent grade. Thus

a 1% equivalent grade tractive resistance means that a car without axle friction or internal mechanism losses would require to be pulled on a level road at a constant stated speed a force of 20 lb per short ton of 2000 lb, in order to overcome the resistance of the tires, road-bed and still-air displacement.

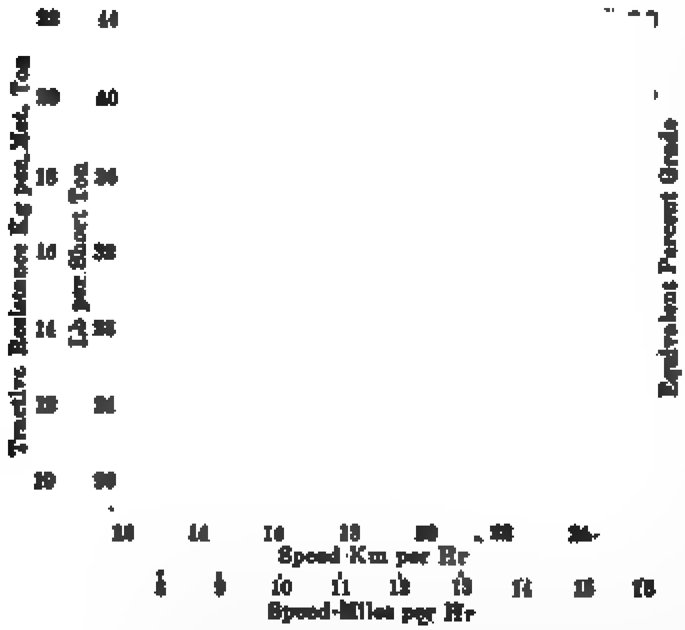

Fig. 1. Summary of Tractive Resistance Tests

"The truck tested was a 1000-lb (450 kg) electrically-propelled delivery wagon equipped with single solid rubber tires, one on each of the four wheels, the tire rating being 36 by 2½ in (915 by 63.5 mm). The tests were made by running the car at, as nearly as possible, constant measured speed, in alternate directions, over selected lengths of standard roads in and near Boston.

"The following urban pavements are enumerated in the order of their desirability for vehicle operation from the point of view of tractive resistance at 12.4 miles per hr, as found in this investigation. (1) Asphalt, (2) wood block, (3) hard smooth macadam, (4) brick, (5) granite block with cement-filled joints, (6) cinder, (7) gravel, (8) granite block with sand-filled joints (see Fig. 1). The presence of a layer of dust, say 1 cm thick, on a fair macadam road, was found to increase the equivalent grade of tractive resistance at a speed of 20 miles (12.4 km)."

Conclusions. From all these figures it is believed, taking into consideration the varying conditions under which all tests were made, as well as the improved character of pavements at present, and remembering that the resistance to traffic increases very much on the bituminous pavements in hot weather, that the following values should be assigned: Granite block 13, wood block 14, brick 15, sheet-asphalt 11, and Bitulithic 12.

11. Slipperiness of Pavements

A great many conditions affect this property, such as cleanliness, temperature, condition of the pavement, whether wet, damp, or dry, etc. Wood block pavement, for instance, while dry, is not slippery, but while wet is exceedingly so, especially if not clean. Then, too, materials can be laid in such a way as to modify materially the normal slipperiness of the pavement. It is, however, an important quality, as it affects directly the efficiency of the horses, if the vehicles are horse-drawn; and if motor vehicles, a pavement may often become so slippery as to be impassable.

Haywood made some very extended observations as to slipperiness in London in 1873. Without attempting to cite in detail the experiments made, the conclusions can be given. The true order of slipperiness is that a horse would travel 132 miles on granite block, 191 miles on rock asphalt, and 446 miles on wood block without accident. It must be understood, however, that the asphalt referred to was the European rock asphalt, which is more slippery than the American sheet-asphalt, and that the soft woods used in Europe are much less slippery than those in America. This is illustrated in Berlin, where the business section is almost entirely paved with rock asphalt, but on the approaches to the bridges over railroad tracks and the River Spree, where there is a grade possibly of 2%, wood block pavement is always laid. In summing up Haywood said: "Taking the whole group of conditions into account, the rock

asphalt was the most advantageously placed, the wood block was the next so, and the granite was the worst placed. On the average of the whole 50 days' observations, the granite block was found to be most slippery, the asphalt, next so, and the wood the least. Separating the accidents under these conditions of surface as regards moisture, it appears that rock asphalt was most slippery when merely damp, and safest when dry; that granite block was most slippery when dry, and safest when wet; that wood block was most slippery when damp, and safest when dry."

Greene, in 1885, had a series of observations made in ten of the principal cities of the United States to determine the relative slipperiness of pavements. From these results it was decided that on pavements in American cities a horse would travel 272 miles on wood block, 413 on granite block, and 583 on sheet-asphalt without an accident. The accidents were divided also into falls upon the knees, falls upon the haunches, and complete falls. On a rough pavement falls upon the knees should not be wholly charged to slipperiness, as a great many must be caused by stumbling. Greene found that, of a total of 84 falls, 68 were upon the knees. Assuming that one-half of the latter were stumbles only, the deduction would be that a horse would travel 698 miles on granite block without an accident due to slipperiness. These results, of course, are general.

Table VI

Kind of Roadway	Maximum Grade
Gravel	12.0%
Broken stone	12.0%
Bituminous surface	6.0%
Bituminous macadam	8.0%
Bituminous concrete	8.0%
Sheet-asphalt	5.0%
Cement-concrete	8.0%
Brick, cement grout filler	6.0%
Brick, bituminous filler	12.0%
Stone block, cement grout filler	9.0%
Stone block, bituminous filler	15.0%
Wood block	4.0%

The Spec. Com. Mat. Road Cons., Am. Soc. C. E. (6c) recommend, in 1918, the maximum limits for grades for different kinds of roads and pavements as given in Table VI.

Table VII.—Number of Cities Using Maximum Grades Given (7)

Percent	Wood Block	Grouted Brick	Sheet-Asphalt	Cement-Concrete	Bituminous Concrete	Bituminous Macadam	Water-bound Macadam
20	..	1	..	1	..	..	..
16	..	..	..	..	..	..	1
15	..	1	..	1	..	..	4
14	..	1	..	1	..	1	1
12	..	..	..	..	1	1	2
11	..	..	..	1	1	..	3
10	..	1	1	1	1	4	3
9	..	1	..	..	..	1	..
8	..	4	..	2	1	2	2
7	1	1	..	2	3	3	..
6.5	..	..	..	..	1	..	..
6	1	4	..	1	8	2	..
5	3	7	9	3	3	2	2
4.5	..	..	1	..	..	..	..
4	3	1	4	3	1	..	..
3.5	..	..	..	1	..	..	..
3	5	1	3	2	..	1	..
2.5	3	..	1	..	..	..	..
2	5	1	..	..	..	..	1
1.5	..	..	1	..	..	..	..
1	1	..	..	..	..	..	..
0.5	2	..	..	..	..	..	..
0.4	..	..	1	..	..	..	..
Total number of cities	24	24	21	19	20	17	19

Conclusions. From these and personal observations, granite block is given a value of 7. wood block 4, sheet-asphalt 5, brick 6, and Bitulithic 6.

12. Favorableness to Travel on Pavements

This is a difficult property to reduce to a cash basis. Some engineers say that the amount of noise made by driving a wagon over different kinds of pavements shows the relative amount of damage caused to the wagon. While this may seem a strange standard, it is a logical one, as it is well known that the smoother the pavement the less noisy it is.

Investigations in the United States. In response to an inquiry as to the difference in wear and tear to delivery wagons and horses when the sheet-asphalt pavements of Brooklyn, N. Y., were increased from 15 to 65 miles in a total pavement mileage of about 500, two of the largest dry goods firms said: (1) "We desire to say that there is a very appreciable difference in our wear and tear account since the increase of asphalt pavements. No more damage has been done to our horses, and of course it goes without saying that the saving to wagons must be very great;" (2) "We beg to state that the effect of the pavements of this Borough has been of such a character as to save us considerable wear and tear on our wagons, and lameness to our horses."

In 1896 the Poughkeepsie Cab and Transfer Co. of Poughkeepsie, N. Y., said in answer to an inquiry: "We would say that our repair bill for 1895 was 50% less than in 1894, and our shoeing bill 42% less in 1895 than in 1894. We attribute this in a great measure to the introduction of smooth pavements in our city." Poughkeepsie at that time had about 28 000 sq yd of asphalt block pavement.

Investigations in London. In 1889 the following two questions were put to the omnibus drivers of London: 1st. Which do you consider the best form of roadway to drive over? 2nd. Which the worst? The answers were: 1st. 750 wood block; 219 macadam; 197 granite block; 51 rock-asphalt. 2nd. 122 wood block; 1 macadam; 13 granite block; 1045 rock-asphalt. It must be remembered, however, that the asphalt pavement is that laid of natural rock and probably subjected to as bad a climate for slipperiness as that of any city in the world. The condition in which a pavement is kept affects different pavements differently. An editorial note in Engineering in 1876 says: "Cornhill was blocked for nearly an hour thru the falling of horses, and the scenes in Cheapside, Eastcheap, Mowgate St., are simply disgraceful, not from the fault of the paving of the roadway, but simply because it is not kept clean." This referred to rock asphalt.

Conclusions. The values given to different pavements are: granite block 2, wood block 5, sheet-asphalt 4, brick 3, and Bitulithic 4.

13. Sanitariness of Pavements

There is a great difference in the sanitary value of the pavements under consideration.

A Committee of the Society of Arts in London, previously referred to, made the following statement on this point: "In urban districts which have been well drained with proper self-cleansing sewers and freed from emanations from them, fever has been found to lurk in those quarters where the surface paving and surface cleaning are bad. On the other hand, the extension of impermeable pavements has been attended with a marked reduction of malarious disease."

In the Old City of New York the number of deaths in 1892 was 44 329, and in 1914, in the same area, the deaths were 43 253, altho the population had increased from approximately 1 630 000 in 1892 to 3 296 197 as estimated by the Department of Health for July 1, 1915. This is a remarkable record, and while of course it is accounted for by the increase in sanitary measures as a whole, the result has been attained to quite an extent by the laying of smooth and sanitary pavements on the East Side and in the tenement districts, where the population is denser than in any other city in the world. It has been possible to keep the streets clean, and they serve largely as recreation grounds for the people in the evenings and on Sundays.

The principles given above are unquestionably correct, and consequently any pavement with a smooth, impervious surface ranks high. Granite block and brick come under that head, but they are noisy, and noise must be considered in this connection. Noisy streets affect one's nervous system,

and a noiseless pavement should be laid in front of hospitals, schools, churches, etc. If the joints of a pavement are open, they allow moisture to collect and street refuse in general to accumulate. This latter decays and gives off not only offensive but dangerous odors.

Conclusions. As a sanitary pavement, then, granite block is given a value of 9, wood block 13, sheet-asphalt 12, brick 10, and Bitulithic 12.

PROPERTIES OF ROADS

14. General Considerations Relative to Roads

The construction of roads in America did not receive much attention until about 1890, when the question of good roads has been brought into prominence by the advent of the bicycle, followed by the introduction of the automobile and its rapid increase both for pleasure and business purposes. The study of the different kinds of roads is more difficult than that of pavements, because the different forms of road construction have not been standardized, even when the same materials have been used, and not enough data has been collected to form a positive and definite idea of the durability of the different kinds or the cost of maintenance. The principles laid down in the selection of materials for pavements are applicable to a certain extent to the selection of materials for roads, but, if possible, the study is even more important, as in the question of pavements a street that is well built up requires a pavement, even if the traffic upon it is not great, for sanitary as well as esthetic reasons, while a road is improved simply on account of its traffic. The principles proposed for road materials are that they shall be cheap, durable, easily maintained, present light resistance to traffic, and be not slippery. Sanitariness, easiness of cleaning, and favorableness to travel are not of great importance, as the roads are in the country and built up to a very slight extent.

Wear of Roads. The GERMAN ENGINEERS reported to the 3rd Int. Road Cong. that the wear of road surfaces produced by fast running passenger motor-cars is due to the following causes: The abstraction of the fine and finest binding and filling materials from the roadway by the suction and propulsion produced by fast revolving wheels, which is the cause of the well known dust nuisance in dry weather and objectionable mud slinging in wet weather. The mechanical crushing of the road material by the heavy blows at very high speeds from the steel rivet heads or studs of the various anti-slipping devices with which the majority of motor-cars are now fitted. The loosening of the top layers of the roadway at sharp bends, generally on the inside, by the gliding motion of the tires producing abrasion and dislocation of the road material, the motion being due partly to the centrifugal force and partly to the rigid connection between wheels and axle. Another cause which they held responsible for the abnormal, violent destruction of road crusts by heavy motor traffic are the iron tires with which some motors and most of the trailers are fitted. It was said that all engineers are asking for regulations specifying that heavy motors and trailers should only be allowed to be built with rubber tires; that it is a fact proved by experience that, owing to the very much higher speeds of mechanically propelled wagons, and their weights being usually heavier than those of wagons drawn by animals, they absolutely ruin macadamized roads with their iron tires, and even roads paved with small setts are damaged by them everywhere, because the tires chip off the edges of the stones. It was stated in this paper that after all these experiences, which extend over many years and are the same everywhere, one is bound to arrive at the conclusion that heavily laden motor wagons no longer wear out ordinary macadamized roads, but very quickly destroy them. This leads to the following verdict, which will hold good everywhere: Ordinary macadam roads are not suitable for the regular traffic of motor-wagons or motor-omnibuses.

The determination of the wear of roads is sometimes made by the amount of material

needed to resurface the roads and sometimes by the actual amount the road crust is worn down. HEWES, in reporting to the 3rd Int. Road Cong., stated that by records which have been kept by the Mass. Highway Comm. on 55 separate sections of macadam road for the 6 years ending in 1907, where the amount of stone required for resurfacing was accurately recorded, it was shown that the annual coefficient of wear was 0.023 tons per sq yd, but that the traffic upon the roads during that period was not known, and that the only information to be derived from these figures was that water-bound macadam roads wore out during an interval of between 6 and 7 years so that they required resurfacing. These roads were largely surfaced with trap rock.

Suitability of Roads for Different Local Conditions. The following opinions were presented by official reporters to the 3rd Int. Road Cong. held in London in 1913.

The Engineer of Alexandria, Egypt, stated that the ideal road may be realized by the construction of a concretional mass of carefully calculated thickness, based on the factors of velocity and weight of the load and the solidity of the subsoil, protected by an elastic and easily renewable wearing surface of just sufficient thickness to give a reasonable number of years' wear, and to resist climatic and vibratory actions. This elastic skin will possibly be much thinner and harder when horse-drawn vehicles have been altogether abandoned.

The French Engineers in their summary state that superficial tarring, which has proved its efficacy in preventing in summer the superficial disintegration of roads under light and fast traffic, has developed greatly, so that it is now important to consider practical means of preserving the coating by repairing the small cracks. When heavy traffic, motor or otherwise, is added to the light traffic, the superficial tarring is no longer sufficient, especially in winter, or on roads ill-exposed, ill-aërated, and constantly damp. Therefore, it is not only necessary to consolidate the surface, but also the body of the roadway. The tar concrete, the bituminous macadam, and the systems related to or derived from them tend to this end, each offering to different degrees these two eminently desirable qualities, the compactness of the mass and the cohesion of the constituent parts. With reference to the economic study of the different road crusts, the report concluded by saying that in the very frequent case of an average traffic, including, however, a proportion relatively important of touring automobiles, it will often suffice, in order to avoid the special damage done by automobiles, to constitute the metalling of relatively soft but binding material, and to adopt limestone aggregates, as these give roads more compact and out of which the detritus escapes with difficulty. Also that if the importance and the nature of the traffic require hard metalling, and if the damages are mainly attributable to fast automobiles, everything points to the need of surface tarring; that this tarring in these cases gives excellent results, as much from the point of view of convenience to the traffic as from the economic point of view: it allows, notably, to get the maximum life out of the metalling compatible with its resistance to crushing, so that there is every advantage in employing very strong materials in surface tarred metalling; that this surface tarring does not give good results unless it is maintained, and that likewise, on lengths where automobile traffic is heavy, it may be advisable to give up the tarring by reason of its too rapid wear and of the difficulty of renewing it at convenient times. It was stated that superficial tarring does not sensibly improve the metalling as regards its resistance to pressure and cannot, therefore, be recommended in the case of heavy traffic. The results obtained from the few cases of consolidated metalling laid down in France lead one to hope that these kinds of roads may be suitable in these cases and that, notably, metalling made up of previously tar-coated materials are likely to provide an economical solution of this question.

The English Engineers reporting on construction in speaking of the relative advantages and use of the different bituminous materials say that the question is too complex to express a definite opinion as to the relative advantages, discussed apart from numerous variations in first cost and durability under different volumes and classes of traffic, as these advantages cannot be ascertained with sufficient accuracy to provide reliable data; that when roads have more than average traffic and of a heavier type, the more expensive pitch, tar, oils, and sand matrix are largely employed by the grouting method with satisfactory results.

WOOD, Engineer of the Borough of Fulham, London, argued, that the material

composing the ordinary water-bound macadam road is in itself a much greater wear-resisting agent than the wood block pavement, but if the quantity of detritus removed each year, exclusive of horse droppings, is taken as an indication of the wear, an average macadam road in his district would wear at the rate of 0.2 in per annum, that is, 33% higher than on the wood paving with only 40% of the traffic. If the wear on the macadam road had been at the same rate as on the wood paving in proportion to the traffic, the actual wear should have been only 0.0125 in. It is therefore inferred that the active force in the deterioration of water-bound roads is chiefly the weather. The engineers also state that when the road is frost-bound the wear of a macadam crust is very light, and consequently draw the conclusion that the binding agent which will successfully resist the effects of the weather is the great desideratum. They also contend that a tar-sprayed macadam crust is much preserved during the summer, but consider that tar is detrimental in the winter as it assists in retaining moisture, and if the tar coating is worn thin the road loosens more readily than an untreated one. This conclusion was disagreed with by CROMPTON of the English Road Board.

DRYLAND, County Engineer, Surrey, considers that the efficiency of surface tarring is relative to the intensity of the traffic, and when this exceeds about 20 000 tons per yd width per annum a bituminous-bound road crust is necessary. It was also found that slag tar concrete satisfactorily carried a traffic of 80 000 tons per yd width per annum, and Trinidad asphalt concrete 200 000 tons per yd width per annum.

BRODIE, City Engineer of Liverpool, has probably given the most attention to the actual wear of the road crust itself by actual measurements, and then, by knowing

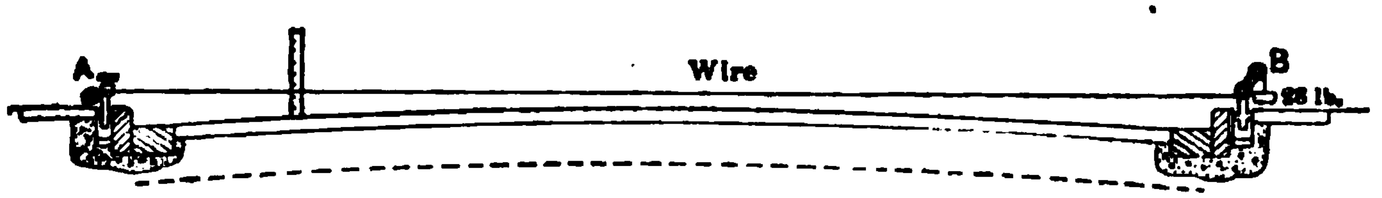

Fig. 2. Method with Wire

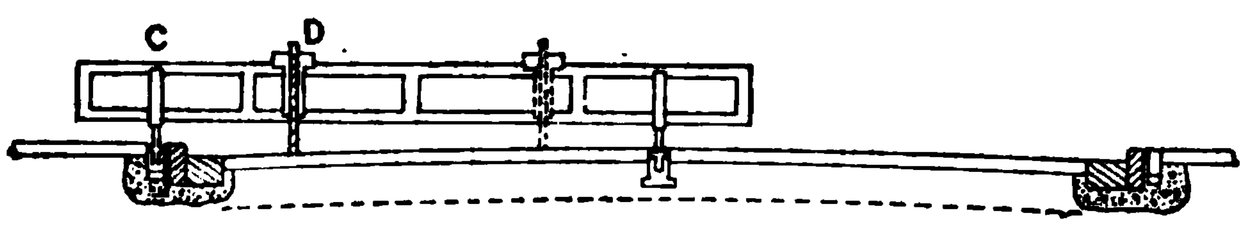

Fig. 3. Method with Straight-Edge

the traffic, is able to learn the effect of the different kinds of traffic. Figs. 2 and 3 show two devices used by Brodie for this purpose, one being a wire stretched tightly, and the other a solid template.

The Italian Engineer concludes his paper on the economic study of the road crusts by saying that in the actual condition of the studies and of practice it is considered that the paving entirely with granite blocks as a road covering gives the best guarantee from the traffic standpoint and from that of a covering on roads with intense and heavy traffic; that superficial tarring is considered appropriate to roads recently rolled and not bearing heavy traffic, but subject to an intense passing of light vehicles and automobiles.

The Swiss Engineer says that on wheel ways within the city other than those in streets with the smallest traffic, surface tarrings have not proved satisfactory, but for country roads the application of surface tarring is, on account of the lessened formation of dust, very much to be recommended, even tho a certain quantity of repairs has to be made every year.

The German Engineers say that, according to all observations made, the wear of macadam roads by light passenger motor-cars still keeps within the limits already reached hitherto on roads where the traffic of animal-drawn vehicles has been brisk and heavy, but that the wear of tar roads caused by light fast running motor-cars is not so great as that caused by vehicles drawn by animal power, because the injurious effect of the animals' shoes is done away with.

From the discussion it will be seen how difficult it is to put a positive value on the different kinds of roads, and also how necessary it is, in order

to determine the proper material for a road crust, to know, not only the quantity, but the quality of the traffic. A country road is improved simply on account of the demands of traffic, and just how it shall be improved will depend upon that traffic as well as the financial ability of the local authorities. Funds are not always available for the road crust that will be the most economical ultimately, but even then the principles underlying road construction should be known and applied as much as possible.

15. First Cost of Roads

The cheapest form of road construction is simply the shaping up of the natural earth and keeping it so shaped thruout the year. This, however, cannot be called really good road construction, nor can any cost be given for original work or for maintenance. It often happens, however, that financial conditions are such, that only such treatment is possible. Another cheap form of construction is what is known as the sand-clay road. This is of two kinds, one where the original soil is sand and clay has to be brought for some distance, and the other, where the original soil is clay and the sand is the material to be brought in. This has been used to quite an extent where traffic is light, and with good results. Its cost varies greatly according to conditions, but Pratt (23) gives the costs of constructing 2563 sq yd of surfacing at 5.21 cents per sq yd, including grading. Here the original soil was sandy and both the clay and sand were hauled in to a certain extent. On another road, where the area was 35 590 sq yd, the cost is given at 5.06 cents per sq yd, the original soil being clay and the sand being hauled. On another road, where the area was 10 000 sq yd and the area surfaced was 6000 sq yd, the cost was 19.6 cents per sq yd. The earth excavation amounted to 3975 cu yd, and the sand used in surfacing was 815 cu yd. It sometimes happens that good gravel can be obtained locally, and consequently a road crust constructed that will give satisfactory results, all things considered, when theoretically gravel would not be a proper material to be used. The cost of this will vary under different conditions, but in general an estimate of 50 to 60 cents per sq yd for a road crust 6 in deep will be a fair average. The cost of repairs will depend, other things being equal, upon the amount and character of traffic. See Sects. 9, 10 and 11 for cost of constructing earth, sand-clay, gravel and broken stone roads.

16. Cost of Maintenance of Roads

In Sects. 9, 10, 11, 13 and 14 will be found data covering the cost of maintenance of earth and sand-clay roads, water-bound gravel and broken stone roads, and gravel and broken stone roads maintained with the aid of dust palliatives and bituminous surfaces respectively.

Examples of the Cost Data on Maintenance of Roads. One of the engineers reporting to the 3rd Int. Road Cong. gives the cost of maintenance on ten different roads for 3 years before motor-omnibus traffic was begun as 12.3 cents per sq yd per year, while in the year following the advent of motor-buses the cost was 25.5 cents per sq yd. While the tonnage was undoubtedly very much increased, there can also be noted that a great portion of this cost was caused by the character of the traffic itself. The figures given for costs by the English engineers show that it costs 1.4 cents to carry a ton a mile on one macadam road and on another one in the same county 0.12 cents only, indicating plainly that the road was not constructed to suit the traffic. The English figures would seem to indicate that when the cost of maintenance exceeded 0.67 cents a ton a mile it was more economical to use stone pavement.

Massachusetts Practice. The cost of maintaining macadam surfaces with cold oil, average of 3 years on about 50 miles, has been $0.0304 per sq yd per year. The cost of

maintaining surfaces composed of mixed sand and oil asphalt, on about 10 miles, was $0.0848 per sq yd per year. This cost, however, includes cost of additional seal coats in a few instances. The cost, not including these seal coats, was $0.025 per sq yd per year. Sohier (24) gives the cost per ton per mile per year on ten different roads in Massachusetts, the cost varying from 0.06 to 0.44 cents. The road costing the least was 15 years old, built of trap rock macadam on a main route. When this road was 8 years old it was resurfaced, and in 1907 ½ gal of the heaviest asphaltic oil that could be applied cold was spread upon the road and properly covered with pea stone and gravel. This treatment was repeated for 2 years, when ¼ gal of heavy hot asphaltic oil was spread upon the road and properly covered. The treatment was repeated once, and the road was said to be in better condition in 1914 than in 1907. The most expensive road for repairs, both per ton and per mile, was a trap rock macadam with heavy teaming. The stones wore down over ½ in in a year. It needed constant patching and was never in excellent condition except when recently resurfaced. It had 2 to 3 in of new stone every 4 or 5 years, and in 1910 it was resurfaced with 3 in of asphaltic macadam at a cost of $1 per sq yd. This road was reported to be in good condition in 1914, but it needed some patching.

17. Annual Cost of Roads

Comparison of Annual Costs of Roads Under Different Traffic Conditions, by Thomas (27).

"A table (see Fig. 4) showing the annual cost and curves for the cost per vehicle-mile of several different types of roads has been prepared and is reproduced herewith. The construction and maintenance costs represent average values from the experience of the Mich. State Highway Dept. during 1915 and 1916, with small amounts added to provide for future betterments. Money is taken as worth 5%. The sinking fund earns 3%, and since most of the roads of Michigan are built with money derived from direct taxation rather than from bond issues it is assumed that the funds will be used for rebuilding or resurfacing as follows: Gravel and water-bound macadam roads resurfaced at the end of 5 years for one-half the original cost, bituminous macadam resurfaced at the end of 10 years for one-half the original cost; concrete resurfaced with bituminous concrete or otherwise rebuilt at the end of 15 years at a cost of $10 000 per mile; brick rebuilt at the end of 25 years at a cost of $13 000 per mile.

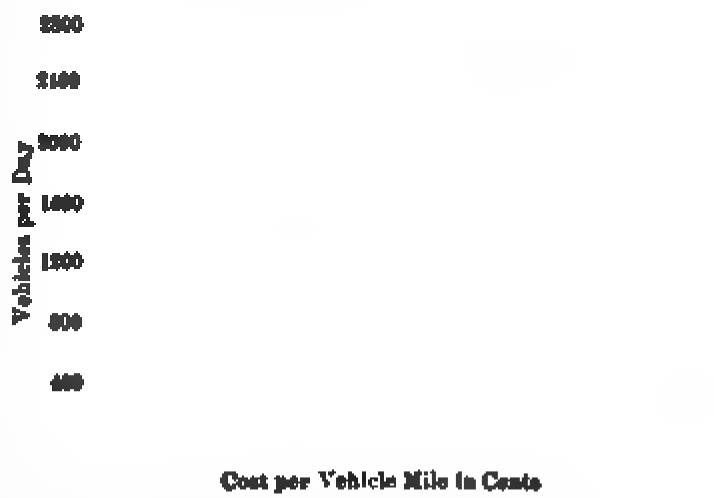

Fig. 4. Cost per Vehicle-Mile for Roads of Different Types

"The curves for the cost per vehicle-mile are discontinued at the points shown because experience has proved that in general the type would not be satisfactory beyond the traffic limits shown. Thus the limit of a 9-ft gravel road is 200 vehicles per day, that of a 16-ft gravel road, 500 vehicles per day, etc. In case a road should be constructed or is serving for a greater number of vehicles per day than the limits given, the maintenance would probably cost more than the values assumed. As the upper limit for concrete and brick is approached a 16-ft road would scarcely be able to care for the traffic, and it might be wise to build an 18-ft road at a slightly greater cost. Hence the upper portion of the curve for brick is dotted.

"**Curves Aid Selection of Road Types.** A number of interesting conclusions are apparent from a study of the curves. With the exception of concrete and brick, which cost nearly the same per vehicle-mile because of the probable longer life and lower maintenance cost of the latter, a type of road may be selected which may be expected

to serve for an appreciably lower cost than others within certain limits. Concrete, for example, should be able to carry the maximum of heavy travel in Michigan, say 2000 vehicles per day, at 0.20 cent per vehicle-mile. But if it were built for 200 vehicles per day, the cost to the county would be 2 cents for every vehicle that passed over the road. Evidently a 16-ft gravel road which would carry this traffic for one-half the cost would be far more economical.

"It is almost an established fact that untreated water-bound macadam will not stand up any better than gravel under a traffic that is composed largely of automobiles, and, as the curve shows, it is much more expensive. When constructed and maintained with a bituminous carpet, however, the life and the traffic limit are raised, and the cost is lowered. Thus treated, macadam forms an excellent intermediary between gravel and the higher types.

"It will be noted that when the traffic is near 200 vehicles per day, the cost of a 16-ft gravel road is about 0.30 cent higher than that of a 9-ft gravel road, but the necessity of providing for future increase would make it advisable to construct the former. Similarly, when the traffic is too heavy for gravel and it is necessary to construct surface treated macadam or concrete the latter being more often built, since the former has not yet attained a wide use in the state there is a great increase in the cost per vehicle-mile. It is desired of course to reduce this variation and keep the cost as low as possible.

"Costs Compared. Reference to the curves show that for the practical limit of a 16-ft gravel road, 500 vehicles per day, the cost per vehicle-mile is 0.40 cent, and that on a bituminous-surfaced macadam for 800 vehicles per day the cost is the same. The difference between the total annual costs given in the table is $466. Theoretically, therefore, if the traffic does not exceed 800 vehicles per day, $466 plus $150, the assumed maintenance for the gravel road below 500 vehicles per day, or about $600 per mile per year could be expended in the maintenance of the gravel road before it would be economical to build bituminous-surfaced macadam, provided that for that sum the road could be kept in a satisfactory condition. Practically, however, a gravel road carrying 800 vehicles per day would be in a continual state of repair and decidedly unsatisfactory.

"Depending on local conditions entirely, the gap between a gravel and a higher-class road may be bridged to a certain extent by paying more for the maintenance. When a county is financially able to build a better road for traffic in excess of 500 vehicles per day it should do so by all means. Without doubt future increase will in time make the road economically suited to the traffic passing over it."

METHODS OF COMPARISON

18. Classifications of Roads and Pavements Based on Traffic

In the light of the foregoing discussion and the general practice in both Europe and America it seems fair to conclude:

That earth roads, shaped up and kept in good condition, as well as sand-clay roads, while serving a good purpose where a community's financial condition or the traffic will not justify much expenditure, cannot be considered as improved road crusts.

That where there is light horse-drawn vehicle and small automobile traffic, water-bound macadam will be fairly successful, and a gravel road even will often be satisfactory.

That where the traffic consists of large touring automobiles in considerable numbers and large horse-drawn vehicles, a bituminous macadam should be used.

That where the automobile and vehicular traffic is heavy and interspersed with a considerable number of automobile trucks, a bituminous concrete road crust, or possibly concrete or brick, as governed by local conditions, will be most desirable.

That where the traffic consists of a large amount of motor trucks, large touring cars or motor-buses, as well as heavy horse-drawn vehicles, concrete or brick road crusts will be absolutely necessary from an economic standpoint, and often regular heavy traffic street pavements.

Assume, for instance, that a road will run from a sparsely settled section to a large and prosperous city. Beginning at the farther end the road will be simply of earth shaped up and kept in condition with wooden drags or other means, followed by a road crust of water-bound macadam, built possibly of local material, even if it be not capable of sustaining much wear. As the road approaches the city and receives increasing traffic, the water-bound macadam should receive a bituminous treatment, which in turn, as required, should be changed to bituminous concrete, Portland cement-concrete, brick, or other permanent material, and, in the vicinity of the city, to as substantial and permanent a street pavement as the particular traffic demands.

Table VIII.—Standards of American Road Builders' Association (5)

Materials	Maximum Traffic	Type	Remarks
Sand............	A1–B1–C1	Asphaltic oil, hot application Calcium Chloride	A temporary form of improvement, if sand is coarse and other durable material not available.
Gravel..........	A2–B2–C3–E1	Asphaltic oil, cold application.	Should have careful maintenance proportionate to traffic; using the log drag weekly—temporary.
Broken stone, soft	A2–B2–C2–D1–E1	Oil, paraffin base	Temporary treatment.
Broken stone, soft	A2–B2–C2–D1–E1	Asphaltic base, cold.	Treatment more lasting.
Broken stone, soft	A2–B2–C3–D1–E1	Asphaltic base, hot.	Treatment more lasting than preceding.
Broken stone, soft	A2–B2–C3–D1–E1	Tar, cold.	Treatment more lasting than preceding.
Gravel..........	A2–B2–C3–D1–E1	Bituminous penetration or mix.	Less constant maintenance required and more durable. Life of surface 5 to 10 years with reasonable care.
Broken stone, hard..........	A3–B3–C3–D2–E2	Bituminous concrete or penetration.	Subject to treatments given under Broken Stone, Soft, but with greater durability.
Concrete........	A2–B2–C3–D2	....	Usually dustless in open country requiring occasional sweeping or scraping in places.
Vitrified brick, stone setts and wood block....	A3–B3–C3–D3–E3	....	....

Table IX.—Classification of Traffic, American Road Builders' Association (5)

1. Horse-drawn, steel tires	A. Light vehicles.	(1) Light, up to 100. (2) Medium, 100 to 200. (3) Heavy, 200 up.
	B. Heavy vehicles, wagons, trucks.	(1) Light, to 75. (2) Medium, 75 to 150. (3) Heavy, 150 up.
2. Self-propelled, rubber tires	C. Passenger automobiles.	(1) Light, up to 100. (2) Medium, 100 to 400. (3) Heavy, 400 up.
	D. Motor-trucks and -buses.	(1) Light, up to 10. (2) Medium, 10 to 20. (3) Heavy, 20 up.
3. Self-propelled, steel tires.	E. Steam lorries and tractors.	(1) Light, 1. (2) Medium, 2 to 6. (3) Heavy, 6 up.

"Opinions of Canadian City Engineers (11a) concerning the suitability of various pavements as they have been used for different conditions of traffic, arranged in descending order of present popularity:

LIGHT RESIDENTIAL TO SEMI-BUSINESS: Sheet-asphalt, Bitulithic, asphaltic concrete, asphalt block, wood block, cement-concrete.

SEMI-BUSINESS TO MEDIUM HEAVY TRAFFIC: Bitulithic, sheet-asphalt, asphaltic concrete, wood block, asphalt block, cement-concrete.

HEAVY TRAFFIC: Brick, wood block, stone block, and scoria block.

ALONG STREET RAILWAY TRACKS: Wood block, brick.

QUIET STREETS: Wood block, Bitulithic, sheet-asphalt, asphaltic concrete.

GRADED STREETS: Brick."

The Mass. Highway Comm. and the engineers of Massachusetts are practically unanimously of the opinion:

"1. That some bituminous binder, either tar, asphaltic oil or asphalt, must be used on highways that have much motor vehicle traffic, to lay the dust and prevent the road from being destroyed, unless a pavement is used.

2. That some form of bituminous or cement-concrete roadway is the best surface to use on main roads where the traffic is not heavy enough to make a stone block, wood block, sheet-asphalt, or brick pavement on a concrete base necessary, or where money cannot be obtained to construct such a pavement.

3. That horses become accustomed to such surfaces and can be much helped by proper shoeing.

4. That separate roadways for motor vehicles and horse-drawn vehicles cannot be built within most of the present highway locations, and that the expense of constructing such roadways is absolutely prohibitive. That such separate roadways are only practical in parkways and possibly in a few cases in or near large cities."

Different Types of Pavements as Recommended by a Committee of Engineers for the Repaving of Boston (25). "CLASS 1. HEAVY TRAFFIC STREETS. Granite blocks laid on Portland cement-concrete base not less than 6 in in thickness, the joints to be filled with Portland cement-grout; in the case of excessive grades, tar pitch to be substituted for grout in the upper inch or so of the joints in order to provide better foothold for horses.

"CLASS 2. MAIN ARTERIES. The same type of pavement as Class 1, with a few exceptions where the surroundings require a smoother and less noisy surface, such as wood blocks or the best grades of bituminous pavements.

"CLASS 3. RETAIL SHOPPING AND OFFICE BUILDING DISTRICTS. Treated wood-block pavements, the best grades of bituminous pavements on a Portland cement-concrete base. At the present time the only wood recommended for wood-block pavements is long leaf yellow pine.

"CLASS 4. RESIDENTIAL DISTRICTS IN THE CITY PROPER. Treated wood-block pavements, the best grade of bituminous pavements or Portland cement-concrete pavements, the choice to be determined by the intensity and character of the traffic.

"CLASS 5. SUBURB AND RESIDENTIAL DISTRICTS. Cheaper types of bituminous pavements, using old macadam surfaces for the base where suitable, or Portland cement-concrete pavements.

"CLASS 6. PARK ROADS CARRYING ONLY PLEASURE TRAFFIC. Bituminous pavements, using old macadam for the base where suitable, or Portland cement-concrete pavements."

Peck, Street Commissioner of Hartford, Conn., (22) assigns the following values to maximum and minimum traffic for which each material is suitable, basing the traffic on the number of units per 24 hr and assuming a 1-horse vehicle as equivalent to 2 units:

Material	Maximum	Minimum
Wood Block	38 000	4000
Grouted Brick	25 000	2500
Sheet-Asphalt	18 000	2500
Bituminous Concrete	15 000	2500
Cement-Concrete	8 000	300
Bituminous Macadam	2 500	300
Water-bound Macadam	1 200	200

Brodie, while Borough Engineer and Surveyor of Blackpool, England, divided the streets within his district into five classes and determined the amount of traffic for which each class was suitable. Conclusions were as follows:

"CLASS No. 1. Foundation of Portland cement-concrete 7 in thick, covered with granite setts 5 in to 6 in in length, 3 in in width, and 6 in depth; jointed with fine, dry gravel and boiling pitch and creosote oil.

"This class is suitable for main suburban roads with traffic up to 200 000 tons per yd width of carriageway per annum; impervious to moisture; noisy, but clean; gradients up to 1 in 40.

"CLASS No. 2. Foundations of Portland cement-concrete 6 in in depth, covered by specially selected Karri or Jarrah blocks 6 in to 8 in length, 3 in in width, 4½ in in depth, laid close, direct on concrete, and grouted with boiling pitch and creosote oil.

"Suitable for first-class shop streets, with traffic of about 100 000 tons per yd width per annum; practically impervious, noiseless, clean, and dustless; gradients up to 1 in 40.

"CLASS No. 3. Foundations of hand-packed rubble 8 in in depth covered with 5 in, of tar-macadam.

"Suitable for residential streets having a light traffic of 20 000 tons per yd width per annum; impervious, noiseless, clean, and dustless; gradients up to 1 in 24.

"CLASS No. 4. Foundation similar to No. 3, but 7 in deep, with 2½-in gauge water-bound granite, to a finished depth of 5 in, blinded with fine granite chippings.

"Suitable for ordinary residential front streets with a light traffic of about 5000 tons per yd width per annum; pervious, comparatively noiseless, dusty, and sloppy; gradients up to 1 in 12.

"CLASS No. 5. Foundations similar to Nos. 3 and 4, 7 in in depth, covered with Haslingden setts, 6 to 8 in in length, 4 to 6 in in width, and 6 in in depth; jointed with dry gravel and boiling pitch and creosote oil; laid with a concave cross-section and channel in center.

"Suitable for back, or secondary access, streets 9 to 18 ft in width, with a traffic of 60 000 tons per yd width per annum; impervious, clean, and dustless; very noisy; gradients up to 1 in 12."

Opinion of British Engineers (28). Table X shows the preferences of engineers in various parts of England for different kinds of road crusts for different traffics, as given in the report of the British engineers to the 3d Int. Road Cong.:

Table X.—Opinions of British Engineers Relative to Adaptability of Different Types of Roads and Pavements

		Metalled Roads Bound with Tar, Pitch, Asphalt or Bitumen			Metalled Roads Water-bound
		Mixing or Grouting	Carpeting Methods	Other Methods	
	exceeding 60 000 tons.	refers grouting to mixing.	Has been successful with carpeting.	Surface tarring only useful for summer months.	Useful only for 3rd class roads having a traffic of 5000 tons per yd of width per annum and under.
Brodie, J. S., Blackpool......	Prefers granite setts for industrial centers where traffic is very heavy. Grit setts for secondary roads.			Spraying only useful for dry weather, and has same defects as carpeting.	
Brownbridge, Birkenhead......	Same opinion as Brodie, J. S.	Prefers this type for lighter traffic and side streets.	Approves carpeting methods.	Surface tarring useful and economical.	Useful on gradients, otherwise its use is rapidly diminishing.
Morgan, Bolton..........	Pre'ers granite setts for heavy traffic in industrial centers.	Does not like grout-			
Lancashire, Leeds	Agrees with above. Grit setts suitable for lighter traffic.				

BULL, Cheshire........	Considers granite setts preferable when water-bound macadam requires renewal under 4 years.	Tar concrete most economical for main roads carrying much motor traffic of light nature. Grouting unsatisfactory.			Suitable only for 2nd class roads subjected to very little motor traffic.
BURGESS, Middlesboro.....	Prefers granite setts for heavy traffic in industrial centers. Grit setts suitable for lighter traffic.	Approves of grouting from point of view of economy and traffic.			Considers this to be an out of date method except for district roads.
HADFIELD, Sheffield........	Prefers setts where annual cost exceeds 6d ($0.12) per sq yd.	Favors mixing methods and coatings 3½ in thick laid in grades, 2¼ in and 1¼ in, or 1½ in in three separate coatings.			Suitable for gradients too steep for tar concrete.
CARPENTER, West Riding.....	Same as Liverpool. Grit setts useful for gradients.	Favors these types from point of view of economy.			Suitable for steep gradients. Would not be tolerated if a cheap cinder were obtainable.
YABBICOM, Bristol........	Suitable for the heavy traffic of vehicles of cities. Most economical.	Considers bituminously bound material improvement over water-bound macadam.			
COL. CROMPTON...	Considers setts only suitable for dock sides and industrial centers.	Believes that for all traffic except the most intense, most acceptable to user and economical to maintain.	Roads having a good strong crust in fair order can be made satisfactorily for modern traffic at lowest cost.	Believes that tar pitch macadam with renewable sand and bitumen topping will be found acceptable to users from the point of economy.	Suitable where there is regular rainfall, no dust nuisance and where good stone is cheap.

19. Tabulations of Valuated Properties of Roads and Pavements

The properties which are possessed by a pavement, the assignment to each its proper percentage value, and the consideration of each pavement in relation to these different values were covered in Arts. 5 to 13 inc. It will now be possible to construct a table that will show in detail how each material stands relative to any other and also what proportion of the properties of a perfect pavement is possessed by each one under consideration. Table XI has thus been formed.

Table XI

	Percentage	Granite Block	Wood Block	Brick	Sheet-Asphalt	Bitulithic
Cheapness	14	8	8	13	14	12
Durability	21	21	16	12	15	15
Easiness of cleaning	15	10	14	15	14	14
Light resistance to traffic	15	13	14	15	11	12
Non-slipperiness	7	7	4	6	5	6
Ease of maintenance	10	10	8	6	6	6
Favorableness to travel	5	2	5	3	4	4
Sanitariness	13	9	13	10	12	12
Total	100	80	82	80	81	81
Less cheapness	....	72	74	67	67	69

It may be said that cheapness is not a physical characteristic, and that in discussing such characteristics of a pavement that item should be omitted. This is true to a certain extent, but as in all cities the cost must be taken into consideration, it has been indicated in the table. Eliminating this item, however, and making wood block, which has the highest value, the standard at 100, the values of the other pavements will be: Granite block, 97; Bitulithic, 93; brick, 91; sheet-asphalt, 91. It must be understood, of course, that this table is a very general one, that much of it is based on personal judgment, and that it will vary in different localities even if the conclusions are agreed to. The important point, however, is not that in this particular case each figure is correct, but that these principles must be studied and applied in considering paving materials. Understanding such principles, it will be possible for an engineer in any locality to construct a table in accordance with personal views and in accordance with local conditions.

The Use of Table XI can be illustrated in several ways. Assume, for instance, a street over which the traffic must be heavy and continuous. Ultimate cost is of great importance. It overrules first cost. Light resistance to traffic and foothold for horses are ruling elements, so that a given power may move its maximum load. The items first to be studied are, then: Durability, maintenance, traction, and the non-slippery property. Consulting the table and combining the values for these items, granite block has a value of 51, wood block 42, sheet-asphalt 37, brick 39, and Bitulithic 39. But when the figures are as close as the last three, ranging from 37 to 39, a careful examination of the remaining properties would be required. In this particular instance granite block ranks so high in the totals, and so far ahead in the general requisites, that it would seem that no mistake could be made in selecting it for the material to be used.

Consider next a residential street, built up with homes, whose owners have means sufficient to afford the best of anything they desire, and, while not wishing to be extravagant, do want and expect the best pavement that can be laid without regard to expense. This is an entirely different proposition. Cost, durability, and maintenance, so important before, can be left out of consideration altogether. Easiness of cleaning, non-slipperiness, favorableness to travel, and sanitariness are the governing characteristics. Working as before, granite block has 28, wood block 36, sheet-asphalt 35, brick 34, and Bitulithic 36. In this instance wood block and Bitulithic have the same values, according to the table, but sheet-asphalt is very close, so that the special qualities of each one should be considered before making a final decision. It may be said that durability and maintenance are too hastily disposed of, and that by considering them the results would be changed. But the basis of selection is that the property owners can afford the best. The problem is to select the best material under existing conditions. The above conclusions would generally hold good for the best retail streets.

Next consider a residence street with very light traffic, where the abutters wish a good but economical pavement, one that will be durable and as near the best that their financial condition will admit. This requires careful consideration. The destructive action of travel is almost wholly eliminated. Durability will be governed by the action of the elements. Every quality but slight resistance to traffic must be taken into account. This gives: Granite block 67, wood block 68, sheet-asphalt 70, brick 65, and Bitulithic 69. Sheet-asphalt leads Bitulithic by one point. It is, however, a somewhat cheaper pavement, and as its characteristics are practically the same, for the conditions specified, a property owner would, undoubtedly select it.

The above examples illustrate the use of the table, showing how it is possible to analyze the conditions that may arise in any case, and how easy it is to arrive at an intelligent and logical result when a systematic investigation is undertaken.

Crosby (13), in studying the different kinds of road crusts, gives values, as shown in Table XII, under the headings of V, W and X, when the figures under V are to be used on main country roads, such as state roads carrying fairly heavy mixed travel; those under W to be used on secondary country roads carrying moderate travel; and those under X to be used on minor country roads carrying farm travel almost wholly.

Table XII.—Showing the Values for Components of Ideal for Different Tables

Components	V	W	X
First cost, cheapness	15	15	15
Maintenance, cheapness	25	25	20
Durability	7	7	7
Ease of maintenance	8	10	10
Cleanliness	5	5	5
Low tractive resistance	10	5	5
Non-slipperiness	10	10	10
Sanitariness	5	5	5
Noiselessness	5	5	5
Acceptability	5	5	8
Favorableness to travel	5	8	10
	100	100	100

Values for four different road crusts for secondary country roads are shown in Table XIII.

Table XIII

Qualities	Values for				
	Ideal (W)	Brick	Plain Cement-Concrete	Bituminous Macadam	Water-bound Macadam
First cost	15	8	10	10	15
Maintenance cost	25	25	20	20	10
Durability	7	7	5	5	3
Ease of maintenance	10	7	8	8	10
Cleanliness	5	3	3	5	2
Low tractive resistance	5	5	4	4	4
Non-slipperiness	10	4	7	5	10
Sanitariness	5	4	4	5	3
Noiselessness	5	3	3	5	4
Acceptability	5	2	3	4	5
Favorableness to travel	8	3	5	6	8
	100	71	72	77	74

Blanchard (2) states that "the primary object of a detailed comparison of the relative merits of various roads and pavements is to enable the engineer to determine within certain limits the method of construction and, in some cases, the method of maintenance which are adaptable to local conditions from the standpoints of economy and efficiency. As an aid in comparison it is advisable to have at hand a table covering numerical values of certain factors which are susceptible to such form of comparison. Table XIV, which illustrates the treatment of the problem along these lines of investigation, gives assigned values for some of these characteristics of the different types of roads and pavements on the basis of ten for the value of the characteristic in an ideal pavement.

Table XIV

	Ideal Pavement	Sheet-Asphalt	Brick on Concrete	Stone Block on Concrete	Wood Block on Concrete	Cement-Concrete	Bituminous [illegible]		Bituminous Surface on Broken Stone	Broken Stone with Dust Palliative	Broken Stone	Gravel	Earth
First cost	10	8	5	1	1	6	7	7	8	9	9	9	10
Ease of traction	10	10	8	3	9	9	9	8	8	6	6	5	2
Non-slipperiness	10	4	8	7	4	6	7	7	7	8	10	10	10
Ease of cleaning	10	10	9	7	9	8	9	9	9	3	3	1	1
Noiselessness	10	7	6	3	9	6	9	9	9	10	10	10	10
Non-productive of dust	10	10	9	8	7	7	9	8	8	6	4	3	1

"It is necessary for each engineer to modify tabular information of this character in order that the values shall be based upon local conditions. For instance, it is obvious that the numerical values assigned to 'First Cost' will vary materially in different sections. It is likewise apparent that it is impracticable to blindly add up numerical values with the expectation that the type having the highest value is the pavement to be employed. In the great majority of cases one or more factors will also have a greater weight than certain other properties. Of course it is possible to weigh the

valuables of a table and then obtain totals for comparison. The totals obtained by the summation of numerical values of properties referred to in the above table must, however, be supplemented by values attributed to factors which are not covered in the table, due to their complex and variable character. As examples of such factors may be cited cost of maintenance, durability, etc, which properties are intimately related to local conditions pertaining to a given highway."

Table XV.—Forest Service, U. S. Dept. Agr., Valuations

Pavement Qualities	Percentage	Granite Block	Sheet-Asphalt	Brick	Macadam	Wood Block
Cheapness	14	4	6½	7	14	4½
Durability	20	20	10	12½	6	14
Ease of maintenance	10	9½	7½	8½	4½	9½
Ease of cleaning	14	10	14	12½	6	14
Low resistance to traffic	14	8½	14	12½	8	14
Non-slipperiness	7	5½	3½	5½	6½	4
Favorableness to travel	4	2½	4	3	3	3½
Acceptability	4	2	3½	2½	2½	4
Sanitary qualities	13	9	13	10½	4½	12½
	100	71	76	74½	55	80

Table XVI.—Canadian Engineers' Valuation of Different Pavements (11a)

Pavement	Percentage	Granite Block	Sandstone Block	Sheet-Asphalt
Cheapness, first cost	14	4.0	4.0	6.5
Durability	20	20.0	17.5	10.0
Ease of maintenance	10	9.5	10.0	7.5
Ease of cleaning	14	10.0	11.0	14.0
Low traction resistance	14	8.5	9.5	14.0
Freedom from slipperiness, average of conditions	7	5.5	7.0	3.5
Favorableness to travel*	4	2.5	3.5	4.0
Acceptability†	4	2.0	2.5	3.5
Sanitary quality	13	9.0	8.5	13.0
Totals	100	71.0	73.5	76.0

Pavement	Asphalt Block	Brick	Macadam	Creosoted Wood Block
Cheapness, first cost	6.5	7.0	14.0	4.5
Durability	14.0	12.5	6.0	14.0
Ease of maintenance	8.0	8.5	4.5	9.5
Ease of cleaning	14.0	12.5	6.0	14.0
Low traction resistance	13.5	12.5	8.0	14.0
Freedom from slipperiness, average of conditions	4.5	5.5	6.5	4.0
Favorableness to travel*	3.5	3.0	3.0	3.5
Acceptability†	3.5	2.5	2.5	4.0
Sanitary quality	12.0	10.5	4.5	12.5
Totals	79.5	74.5	55.0	80.5

*Favorableness to travel is dependent chiefly upon smoothness and freedom from dust and mud; secondarily upon the qualities composing ACCEPTABILITY.

†Acceptability includes noise, reflection of light, radiation of heat, emission of unpleasant odors, etc. It chiefly concerns the pedestrian and the adjoining resident."

Table XVII.—Adaptability of Roads and Pavements to Different Types of Streets and Traffic by Fixmer (16)

Kind of Pavement or W Surface		Kind of Foundation or Base	Kind of Filler in Joints	Estimated Life in Years	Note A Type of Streets Used on or Suitable for:	Note B Kind of Traffic Pavement is Suitable for:
5 in Granite block	2 in Sand	8 in Concrete	Tar	30	1-5-7	U-W-X
Modern granite block	1 in Mortar	6 in Concrete	Cement	(25)	1-3-5-9	V-W-X-Z
Creosoted wood block	½ in Mortar	6 in Concrete	Tar or asphalt	10-20	3-5-4-9	U-X-Z
Brick	2 in Sand	6 in Concrete	Asphalt	20	5-7-9-11 6	V-X-Z-(U)
Modern brick	1 in Mortar	6 in Concrete	Cement	25	5-7-11-6-8-10	V-X-Y-Z
Monolithic 3 in brick	½ in Mortar	4 in Concrete	Cement	(20)	(7) 11-8 10	X-Y Z
Sheet-asphalt	2 in Top 1½ in Binder	6 in Concrete	....	20	2-4-6-8	V-X-Y-Z
Sheet-asphalt	1½ in Top 1 in Binder	5 to 6 in Concrete	....	15	11-4-6-(10)	X-Y-Z
Asphaltic concrete	2 in Top	6 in Concrete	...	12	11-4-6-2	X-Y-Z
Cement-concrete	Reinforced	7 in Average	With tar surface	(10)	11-8 10-12	V-Y
Bituminous macadam	2½ in Top	8 in Stone	Asphalt or tar	(8)	11-10-12	X-Y
Water-bound macadam	2 in Top	10 in Stone	Water and screenings	(5-10)	(10)	X

Note: Figures in parentheses are questionable.

Note A: Types of streets usually present in cities may be designated as follows:

Business Streets		Residence Streets	
Common Classification	Symbol	Common Classification	Symbol
Heavy railroad dock, warehouse		Boulevards, pleasure drives	2
	1		4
	3		6
	5		8
	7	Short, or local traffic streets	10
	9	Private roads and park drives	12
	10		

Note B: Kinds of traffic usually present in cities may be classified and designated as follows:

Heavy weight slow moving rolling type	U
Heavy weight fast moving shearing type	V
Large number heavy fast moving mixed type	W
Light weight slow moving rolling type	X
Light weight fast moving shearing type	Y
Large number light fast moving mixed type	Z

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SECTION 25

SIDEWALKS, CURBS, GUTTERS AND HIGHWAY SIGNS

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SIDEWALKS

1. General Data Relative to Walks

A Sidewalk is a pavement designed solely for pedestrian traffic. The same qualities that go to make up a good pavement for vehicular traffic are necessary for sidewalks. Foot pavements are not subjected to such heavy loads as roadway pavements, but the destructive action of water and frost is the same in both cases and the various factors that enter into the construction of roadways must also be considered in the construction of a sidewalk.

The Essential Qualities of a good sidewalk are: Smoothness without slipperiness; non-absorption; durability; cleanliness; uniformity of wear; low first cost; ease of repair.

Materials generally used for sidewalks are cement-concrete, brick, stone flags, tar and asphaltic concrete, sheet-asphalt, asphaltic mastic, cinders, broken stone, gravel and wood planks. By far the greater proportion of sidewalk construction consists of cement-concrete, brick and flagging. Cement-concrete is rapidly displacing all other materials for sidewalk work.

The Width of sidewalks should be proportioned with reference to the volume of pedestrian traffic and the total width of the street. The general

practice is to make each sidewalk from 1/6 to 1/4 the total width of the street between property lines. On suburban streets, widths of from 4 to 6 ft are generally sufficient. For solidly built up residential streets, the walks should be from 8 to 12 ft and on important thorofares as much as 15 ft in width.

Location of Paved Sidewalk. On business streets the sidewalks generally extend from building line to curb. On residential streets it is usual to pave only a portion of the space between the curb and building line. The walk may be laid next to the building or adjacent to the curb. The latter location has the advantage that the unpaved parking back of the walk practically becomes part of the front yard and will be cared for by the householder. To provide for trees, unpaved pockets from 3 to 4 ft in width and from 5 to 8 ft in length should be left at suitable intervals along the curb, or a continuous unpaved strip may be left between the curb and sidewalk.

Relation of Sidewalks to Shade Trees (21). "The position of a sidewalk effects fundamentally the successful accomplishment of street tree planting. There are but three places where a walk may be placed: About the center of the allowed space, against the curb, or against the property. On account of a wide-spread ignorance of the importance of the matter, the general method is to place it directly in the center, or within 2 ft of the curb. A 60-ft street has a sidewalk space 12 ft in width, while a 50-ft street has one of 10. Allowing for a 5-ft flagstone, the space remaining for parking is 7 or 5 ft respectively. This space, if kept intact, provides sufficient room for the successful planting of any species of shade trees. If, however, the walk is put down in the center, the 7-ft and 5-ft spaces are split in two sections, both of which are inadequate for the proper growth of a good tree. The habit of placing walks in the center, therefore, allows a perfectly good strip of land between the curb and walk, or between the walk and property, to be wasted, and the custom should be abolished. There remains a choice between the two other locations, concerning which opinion is divided.

"The POSITION OF TREES must now be either inside or outside the walk. It is agreed that inside planting improves the appearance of the property, but adds little to the appearance of the street; that outside planting improves directly the street alone. The advocates of curb sidewalks and inside planting state the following advantages: The trees require no guards, and the roots have more room; the trees are out of danger from vehicles; it does away with the keeping up of the outside parking space; more moisture is supplied the young trees, and there is less injury inflicted by wires, leaking gas and sewer mains. Most of these claims are logical, but the street still shows a barren look, and an excessive width of paving without a break. Therefore, if the street is to be considered first, the proper position for the sidewalk is against the property, while the trees are placed near the outside line of the walk. The advantages of placing the sidewalk as far away from the curb as possible are as follows: The excessive expanse of bare asphalt is broken, thereby beautifying the street; pedestrians are not subject to being splashed by automobiles and trucks, the most serious indictment against curb-placed sidewalks; the shade trees hide, to a very great extent, the hideous poles lining the curb; the roots of trees are not so liable to injure the lawns of property holders by growing too close to the surface."

Slope. Sidewalks must have sufficient transverse slope to shed water quickly. Whenever practicable, the slope should be toward the curb. When necessary to slope away from the curb, a shallow gutter should be constructed at the back of the walk leading to sewer traps or cross-drains under the walk. The slope should be from 1/4 to 1/2 in per ft, depending on the smoothness of the surface of the walk. Cement-concrete walks should have a slope of about 1/4 in, flag and brick walks from 1/4 to 1/2 in per ft. Greater slopes than 1/2 in are noticeably uncomfortable and are apt to cause slipperiness.

Report, Com. Am. Soc. Mun. Imp. (9). "A slope of 1/4 in per ft from back to front of walk, dropping towards the curb, is recommended for the paving. A slope of 1 in per ft should be allowed the parkways to provide sufficient drainage from the walk."

"Sidewalk Steps (14a) are often necessary on steep-grade streets in hilly towns. As people walk faster out of doors, the steps should be considerably wider than those in buildings; and the writer advocates 15-in treads and 6-in risers. In one Minnesota town there is a long flight of steps with 40-in treads. Steps with 15-in treads, in series separated by landings, would have been better."

Park Walks. The same principles and methods of construction used for street walks should be applied to the construction of park walks. Being subjected to less severe usage by traffic but to greater exposure to the action of water, they are usually made of lighter construction and provided with better drainage facilities than street walks. Park walks are usually built with a crown of from ¼ to ½ in per ft to shed the water to both sides, and are lined on one or both sides with shallow gutters of brick or small cobbles. Cement-concrete, asphalt tiles and gravel are the materials most commonly used in their construction. Cement-concrete, on account of its stiff and artificial appearance, is generally limited in use to the walks of heaviest traffic.

Table I.—Character and Cost of Sidewalks in 1915 in Several Cities

From *Municipal Journal*, Feb. 3, 1916

City	Material	Thickness in Inches	Sq Yd	Price per Sq Yd
San Francisco, Cal.	Broken stone	...	10 812	$0.59
Denver, Colo.	Cement-concrete	4	119 060	0.95
Live Oak, Fla.	Tile	...	2 600	1.40
Indianapolis, Ind.	Cement-concrete	4	85 020	1.59
Manhattan, Kan.	Brick	...	420	0.72
Waterville, Me.	Tar concrete	...	990	0.60
Everett, Mass.	Brick	...	5 853	1.25
North Adams, Mass.	Tar concrete	...	4 102	0.28
Woburn, Mass.	Granolithic	4	1 699	1.55
Duluth, Minn.	Cement-concrete	4	17 000	1.20
Laconia, N. H.	Tar concrete	4	90 000	0.60
Elizabeth, N. J.	Stone	...	25 000	0.68
Albany, N. Y.	Cement-concrete	...	22 420	1.62
Albany, N. Y.	Stone	...	3 770	1.80
Albany, N. Y.	Brick	...	10 085	0.90
Richmond, N. Y.	Stone	...	14 444	2.25
Cleveland, Ohio	Cement-concrete	4½	24 346	1.00
Toledo, Ohio	Stone	...	13 840	1.06
Oklahoma City, Okla.	Brick	...	26 400	0.50
Marshfield, Ore.	Wood	...	4 090	0.38
Pittsburgh, Pa.	Cement-concrete	5	17 484	1.26
Bennington, Vt.	Tar concrete	...	397	0.75
Port Townsend, Wash.	Wood	...	524	0.56

2. Cement-Concrete Walks

Cement-concrete sidewalks, also termed granolithic and cement walks, more nearly meet the requirements of a good walk than any other type of sidewalk construction. While requiring some skill and careful attention to details in construction, they are of moderate cost and, when properly laid, are smooth, durable and attractive in appearance. They possess the further advantage that the materials for their construction and repair are readily available in practically all localities.

A Granolithic Walk is one in which the aggregate of the mortar wearing surface is composed in whole or part of stone screenings.

The Essential Features in the construction of a cement-concrete walk are: A firm, but porous foundation; a base of well made, strong cement-concrete; a wearing coat of rich mortar finished to a smooth dense surface and the division of the walks into blocks with lines of weakness between them along which all cracks will occur.

The Foundation or frost base is designed primarily as a means for disposing of water which would otherwise accumulate under the walk and result in its being moved by frost. When drainage of the natural soil is good, no base is necessary. In soil where the base and natural drainage can not take care of the water, drains of stone or tile leading into available sewers should be provided to prevent the accumulation of water in the base. In grading for the foundation all loose or spongy places should be cut out and their place filled with suitable material. The subgrade should be trimmed to a transverse slope of about ½ in per ft and well compacted by ramming or rolling. Fills should be made in layers not over 6 in in thickness and well consolidated. The fill should be carried at least 1 ft beyond the edge of the walk to protect the foundation from being undermined by wash.

MATERIALS generally used for foundations are sand, broken stone, brick, gravel or cinders, the latter being the most common. Only steam or black cinders should be used; household ashes are not suitable.

The DEPTH of foundations varies from 3 to 12 in. As a rule a depth of 6 in is sufficient. The foundation should be thoroly compacted by tamping or rolling. Cinders should be wetted to assist in consolidation. The finished surface of the foundation should be parallel to the top of the walk.

Cement-Concrete. The concrete base is generally made from 3 to 4 in thick. A thickness of 4 in is recommended. Proportions of 1 : 3 : 6, 1 : 2½ : 5, 1 : 2 : 5, and 1 : 2 : 4 are commonly used. Proportions of about 1 : 2 : 5 are recommended. Excerpts from the 1912 specifications of the Assn. Standardizing Paving Specifications follow:

"**The Fine Aggregate** shall consist of any material of silicious, granitic, or igneous origin, free from mica in excess of 5%, and other impurities, and shall be of graded sizes ranging from ¼-in down to that which shall be retained on a 100-mesh sieve, not more than 20% of which will pass a 50-mesh sieve for the base; and from ¼-in down to that which will be retained on a 80-mesh sieve, nor more than 20% of which shall pass a 50-mesh sieve for the top or wearing surface.

"**The Coarse Aggregate** shall be sound gravel, broken stone or slag having a specific gravity of not less than 2.6. It shall be free from foreign matter, uniformly graded and of sizes that will pass a 1-in screen and be retained on a ¼-in screen.

"**In Preparing the Concrete for the Base**, the cement and aggregate shall be measured separately, and then mixed in such proportions that the resulting concrete shall contain fine aggregate amounting to one-half of the volume of the coarse aggregate; and that 5½ cu ft of concrete in place contain 94 lb of cement. The top or wearing surface shall be composed of 1 part Portland cement and 2 parts fine aggregate, mixed with sufficient water to produce a mortar of a consistency which will not require tamping, and which can be easily spread into position with a straight-edge."

Forms. The concrete is laid between side forms, usually made of wood. The upper edges of the forms should be in the plane of the top surface of the walk and the forms should be securely staked so as to hold to line and grade. When the walk abuts a curb which is on line and grade, the curb may be utilized as a form. If the walk is laid solid from curb to building, a narrow strip should be placed against the curb, to form an expansion joint.

Placing the Concrete. As soon as the concrete is laid between the forms, it should be thoroly tamped and the surface made exactly parallel to the top of the walk and at a depth below it equal to the thickness of the mortar

wearing course. The concrete should be wet enough to tamp without causing a film of cement to flush to the surface. The surface of the concrete base should be left rough so as to get a good bond with the mortar topping. If the foundation is dry and especially if it consists of cinders, it is well to wet it throroly before laying the base in order to prevent the absorption of water needed by the concrete.

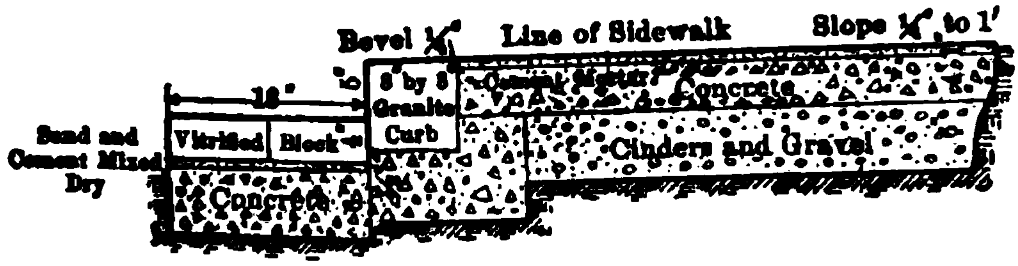

Fig. 1. Cement-Concrete Sidewalk, and 8 by 8 in Curb and Brick Gutter on Concrete Base

The Wearing Course consists of a rich mortar of cement, sand, granite, or trap screenings or a mixture of sand and screenings. Proportions of 1 : 1, 1 : 1½, and 1 : 2 are generally used. The 1912 specifications of the Assn. Standardizing Paving Specifications are as follows:

"The top or wearing surface shall be composed of 1 part Portland cement and 2 parts fine aggregate mixed with sufficient water to produce a mortar of a consistency which will not require tamping and which can be easily spread into position with a straight edge."

While a rich mortar is essential, an excess of cement is liable to cause crumbling or scaling of the surface. Screenings make a more durable surface than sand and one more nearly resembling natural stone. Sand is cheaper and if of good quality is satisfactory for ordinary conditions. Special care must be taken to keep the aggregate free from mud lumps, dirt, chips and leaves which will cause the formation of unsightly and injurious pits in the surface that can not be repaired.

The THICKNESS of the top course varies from ½ to 1 in. One inch is recommended for standard construction. The fresh mortar should be spread on the concrete base before the latter reaches its initial set, worked to grade with a straight-edge and beaten and worked with wooden floats so as to produce as dense a mortar as possible. The surface should be finished with toothed roller, wire brush or trowel as desired. The trowel surface while harder is not so pleasing on account of its glaze. Care must be exercised that the mortar is not so wet as to delay the finishing, as very wet mortar can not be floated and finished. The mortar should be of such consistency that it can be easily worked with a straight edge. An excess of water may be removed by working into the mortar a mixture of dry sand and cement of the same proportions as the mortar. Neat cement should not be used to take up excess water.

Concrete walks are always divided into blocks or slabs, usually square, containing from 9 to 36 sq ft. Small blocks are preferable to large blocks, as they are less liable to crack and are more easily repaired. With small blocks, cuts for trenches or repairs can be made along the joints thus enabling a neater repair to be made.

Joints should be continuous both longitudinally and transversally. Various methods of making the block divisions are used. One method is to construct wooden or metal forms the size of the blocks and lay and finish each block separately. Another method is to lay the base in separate blocks divided by narrow forms which are immediately withdrawn and the joints filled with sand. The top is then laid monolithic and joints cut in the top over those in the base. The following method, which is the cheapest and gives good results if carefully done, is coming into general

use: The base is laid monolithic between the side forms and divided into blocks by the use of a broad bladed tool cutting entirely thru the concrete, and the joints thus formed are filled with sand. The top is then laid as a monolith and joints cut in it exactly over the joints of the base. The location of the joints is accurately marked on the side forms and on transverse strips nailed to them, and the cutting tool is guided by a straight-edge. This method is especially adapted when gravel concrete is used for the base, as there is less tendency to fracture the concrete than in the case where the cutting tool has to displace a sharp angular aggregate. If the joints are not cut entirely thru the top course, there will be less liability of water entering the base. Furthermore the partially cut joint provides a plane of weakness along which fracture will occur in case of settlement or contraction.

Expansion Joints should be provided where necessary. It is usual to specify joints about every 50 ft. By the exercise of judgment this interval can be increased, and as such joints are always objectionable in a walk their number should be kept at the minimum needed to prevent damage to the walk or abutting curb from excessive expansion. Local conditions of temperature, the amount of exposure or shade, and probably the conditions of temperature and weather, at and immediately subsequent to the laying, affect the amount of expansion or contraction. Joints should be provided where the walk abuts a curb at a street or alley return. Expansion joints are formed by a thin plank which should be withdrawn after the concrete has set and the joint filled with sand or a bituminous filler. Insufficient provision for expansion is generally manifested by pushing out the curb at corners or by buckling at a joint. In such case the walk will not contract to its original position and on the other hand if it is cut off and the curb reset no further buckling or damage to the curb will occur from expansion.

Coloring Matter is usually added to the surface to reduce the unpleasant glare of the natural color of new concrete. Lampblack is generally used for the purpose. Proportions of from 2 to 16 lb per barrel of cement will produce colors varying from light slate to dark bluish slate. If it is desired to have the color permanent, the coloring matter should be incorporated in the entire wearing course by mixing it with the dry cement and fine aggregate before making the mortar. A common method is to add the coloring matter to a mixture of dry sand and cement of the same proportions as used in the wearing course. This mixture is sprinkled over the wearing course after it is in place and then floated and troweled into the surface, repeating the operation until the desired shade is obtained. Tho the color applied in this way will gradually wash out, by the time it has disappeared the walk will have become darkened from usage. When new blocks are laid in repairing a walk they should be made slightly darker than the walk to allow for bleaching. Neat coloring matter should never be applied to the surface as it will cause flaking. Different colors can be produced by use of proper coloring matter. Table II of colors and proportions is given by L. C. Sabin.

At Alley and Driveway Crossings the wearing surface should be finished, with a groover, in blocks about 4 in square, both for a foothold for horses and to attract the attention of pedestrians. Crossings for heavy traffic should be laid with vitrified or granite block. Driveway and alley pavements should be laid flush with the top of the sidewalk to a point near the curb, in order not to introduce a step in the line of the walk.

Protection of Green Concrete. Precautions must be taken to prevent the fresh surface from being pitted by rain. When completed, the walk should be be kept moist and protected from traffic and the elements for at least 3 days.

Freezing. On account of the exposed location and small mass of concrete in this class of work it is particularly liable to injury when laid in freezing weather and special precautions should be taken in mixing and laying under such conditions.

Single-Course Walks. Concrete walks are sometimes constructed as one-course work. A richer and wetter mixture should be used than for two-course work, the best proportions being about 1 : 2 : 3. Slab divisions should be made as in the case of two-course work. The concrete should be well tamped, struck off and smoothed even with the top of the form. The coarser particles of the aggregate should then be tamped into the surface, with a form of tamper designed for the purpose, a sufficient depth to permit the walk to be finished as in the case of two-course work.

Table II.—Colored Mortars

Colors Given to Portland Cement Mortars Containing Two Parts River Sand to One Cement

Dry Material Used	Weight of Dry Coloring Matter to 100 Lb Cement				Cost, in Cents of Coloring Matter per Pound
	½ Lb	1 Lb	2 Lb	4 Lb	
Lamp black..	Light slate..	Light gray...	Blue gray...	Dark blue slate......	15
Prussian blue	Light green slate......	Light blue.. slate......	Blue slate..	Bright blue slate......	50
Ultramarine blue......	....	Light blue slate......	Blue slate...	Bright blue slate......	20
Yellow ochre	Light green	....	....	Light buff..	3
Burnt umber	Light pinkish slate.......	Pinkish slate	Dull lavender pink...	Chocolate...	10
Venetian red	Slate, pink tinge......	Bright pinkish slate...	Light dull pink......	Dull pink...	2½
Chattanooga iron ore...	Light pinkish slate.......	Dull pink...	Light terra cotta.....	Light brick red.......	2
Red iron ore.	Pinkish slate	Dull pink...	Terra cotta..	Light brick red.......	2½

Failures of cement-concrete walks, assuming good materials in proper proportions are used, can generally be ascribed to one or more of the following causes: Poor drainage of foundation; inadequate provision for expansion and contraction; lack of bond between the concrete base and mortar top and imperfect jointing between slabs. Strict attention to all details in the execution of the work is essential to prevent failure from these and other causes.

Vault Work. Concrete, in the form of plain or reinforced slab construction, is particularly adapted for sidewalk work over vaults. This class of work, involving as it does special features of design and construction, is more properly a subject of building construction.

Cement-Concrete Plates as Laid in Germany (22). "Square concrete plates laid so that the diagonal of the square is at right angles to the direction of the walk is an

arrangement much used, with a border of plates in the shape of bishop's caps. Another arrangement noticed was the use of oblong and square plates laid so as to break joints. The squares are either 12½, 16½ or 20 in, depending on the width of walk desired, and the oblong plates 16½ by 25 in. The thickness of these plates is about 2 in. They are made of cement, sand and fine crushed stone-granite, basalt or diabase and are manufactured in machines under high pressure."

The Specifications of Pittsburgh are, in part, as follows:

"Concrete sidewalks shall consist of a foundation of gravel or broken stone 5 in in depth, and a slab of Portland cement-concrete 5 in in depth. The sidewalks shall be laid in general with a slope of ¼ in per ft from the curb line to the building line.

"The Foundation Course shall be 5 in and shall consist of clean gravel or broken stone which shall be free from dust, dirt or other foreign matter. The material shall range in sizes from 2½ to ⅜ in. The foundation course shall be thoroly rammed or rolled and then leveled off so as to be paralleled with the finished surface of the sidewalk. Cinder or clinker where used for foundation, shall be of acceptable material approved by the Director, of the sizes hereinabove specified for gravel or broken stone and shall be free from dust, fine ash or other objectionable or foreign matter.

"Cross-Drains. When the sidewalk pavement does not extend to the curb, cross-drains 10 in by 12 in in section shall be provided at intervals of 25 ft so as to connect the foundation of the sidewalk with the broken stone curb drain. These cross-drains shall be filled with stone or gravel which will pass a 3-in screen.

"The Concrete Masonry in the sidewalk shall be 5 in in thickness. The concrete shall be mixed in the proportions of 1 volume of cement, 2 volumes of sand and 4 volumes of gravel or broken stone. The gravel or broken stone shall be uniformly graded from fine to coarse and shall all pass a 1¼-in screen and be retained on a ¼-in screen. The sand shall preferably be coarse and in no case shall more than 3% of the same pass a 100-mesh sieve. Sufficient water shall be added so as to produce concrete of a consistency which can be readily worked and finished in a manner hereafter required. The sidewalk slabs shall not be more than 6 ft in length, nor shall they contain more than 36 sq ft of surface area. After mixing, the concrete shall be handled rapidly and each slab finished in one continuous operation. The concrete shall be deposited between cross-forms, forming slabs of the dimensions hereinbefore required, and shall be properly tamped against the forms. The coarse material in the concrete shall be forced down with a special tamper and the surface of the sidewalks shall then be struck off by means of a strike-off board which shall be moved along the side forms. Care shall be exercised to prevent the accumulation of coarse material in front of the strike-off board, and to insure the placing of good dense concrete thruout the slab. The cross-forms shall be withdrawn when the concreting of the next slab is commenced, the location of the joints being marked on the side forms. The surface shall be finished with a wooden float, care being taken to thoroly compact the concrete and the wearing surface, when finished, shall have a moderately rough surface. On steep grades the surface shall be roughened, as ordered by the Director in the field. Working with a steel trowel is expressly prohibited. After the concrete has set sufficiently, the slab divisions shall be cut the entire depth of the concrete and the joints filled with dry sand. All edges of the slab shall be finished to a radius of about ⅜ in. The application of cement to hasten hardening is prohibited. Excess water shall be removed with a rag or mop. The contractor may, if he so elects, lay the sidewalk in alternate blocks.

"An Expansion Joint ⅜ in in width shall be provided every 50 ft, but in all cases an expansion joint shall be placed at each end of each section of walk. The expansion joints shall extend the full width of the sidewalk and the full depth of the slab and shall be filled either with bituminous joint filler conforming to requirements, or a suitable and approved strip filler.

"After the pavement is completed the contractor shall use suitable means to prevent damage to the finished surface and shall keep it moistened with water for at least 4 days."

St. Louis Specifications for Expansion Joints at Curbs are as follows: "Where the sidewalk pavement will touch curbs at street intersections or paved alley aprons, the bottom course of concrete and the wearing surface shall be separated from the curb or the alley pavement by a layer of pre-molded expansion joint material which shall fulfill the following specifications: Expansion joints shall be composed of asphalt or pitch in combination with either fiber or with a fine mineral aggregate. If a mineral

aggregate is used, none of the particles shall be of such size as to be retained on an 80-mesh sieve. The joints shall be pre-molded in the form of a board ⅛ in thick, and of a width equal to the entire depth of the granitoid pavement. The consistency of the mixture in the completed joint shall be in accordance with that of the sample on file in the Office of the President of the Board of Public Service. Joints shall be made up in strips not less than 2 ft in length, and shall not vary appreciably from the specified thickness of ⅛ in. This joint shall extend to the full depth of the bottom course of the sidewalk pavement, and should the concrete foundation of the curb or alley pavement be at or above the bottom of the concrete base of the sidewalk pavement, it shall be picked down to below that level, and shall be separated by a layer of tar-paper or other material satisfactory to the Engineer."

Cost Data. The cost of cement-concrete walks, including excavation for the depth of the walk and gravel or cinder foundation, varies from about $0.80 to $1.50 per sq yd (see Table I, Art. 1). The details of cost to the contractor in Webb City, Mo., of constructing a two-course cement-concrete walk, not including cinder base, follows (29): The first course was 1 : 3 : 5 concrete, 3¼ in thick; the wearing course was 1 : 1½ mortar, ¾ in thick.

Labor and Materials for 9567 Sq Ft

" Labor:	Cost per Sq Ft
1 foreman, 54½ hr at $0.666	$0.0038
1 finisher, 68½ hr at $0.444	0.0080
2 mixing mortar, 104 hr at $0.222	0.0024
2 feeding mixer, 109 hr at $0.222	0.0025
2 wheeling mortar and concrete, 125 hr at $0.222	0.0029
2 placing concrete and mortar, 119 hr at $0.222	0.0028
Total for labor	$0.0174
Material:	
Cement, concrete and mortar, 748 sacks at $0.40	$0.0313
Sand, mortar, 467 cu ft at $0.08	0.0039
Gravel, concrete, 97 cu yd at $0.50	0.0051
Total for material	$0.0403
Total for labor and material	0.0577 "

3. Brick Walks

Brick sidewalks are generally constructed of building brick. While vitrified paving or sewer brick are better, their cost prevents their use except in cases where architectural or traffic considerations call for a special treatment. Building brick for sidewalks should be a hard burned dark red brick, as far as practicable of uniform hardness and size, as a variation in hardness causes uneven wear, while uniformity in size greatly reduces the labor of laying.

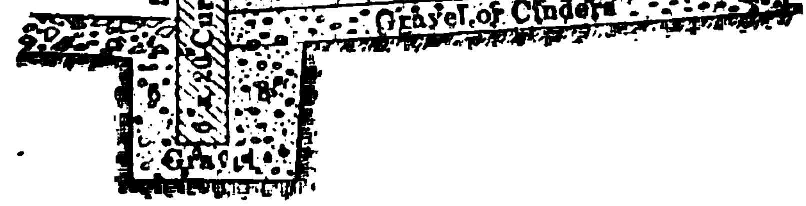

Fig. 2. Brick Sidewalk and 6 by 20-in Curb on Gravel Base

Construction. A foundation of gravel or cinders about 6 in in thickness should be provided for the walk. The work of preparing the subgrade and constructing the foundation should be similar to that for a cement-concrete walk and the same degree of care used (see Art. 2). The bricks should be bedded in a 2-in layer of clean sand spread over the foundation and brought exactly parallel to the surface of the finished walk. The bricks should be laid on their side by pavers kneeling on boards on the part of the walk already laid. The bricks may be laid either at right angles

to the line of the walk (see Fig. 3) and so as to break longitudinal joints, or in herring-bone pattern (see Fig. 4). A herring-bone walk has a more finished appearance and will hold a more even surface than the rectangular walk. It requires greater care in laying and more labor and material for cutting and is consequently slightly more expensive. When the walk does not abut a curb or coping, it should be protected by a course of brick laid on edge. A light covering of fine dry sand should be spread over the walk as soon as the bricks are laid and the bricks brought to a firm bearing by placing a plank over several courses and ramming with a heavy rammer. After the ramming is completed the walk should be covered with about ¼ in of fine sand which should be broomed into the joints. Any excess sand should be allowed to remain to be worked into the joints by rain and traffic. In dry windy weather this sand should be sprinkled to prevent its loss and the annoyance due to the blowing sand. Driveway and alley crossings should be paved with the brick laid on edge and if the traffic across the sidewalk is heavy, vitrified paving brick with grouted joints should be used.

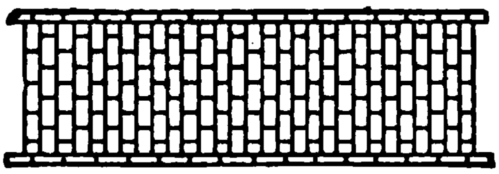

Fig. 3. Brick Sidewalk, Rectangular Pattern

Boston Specifications are as follows: "The bricks to be used are to be burned hard entirely thru, straight-edged, of compact texture and regular and uniform in shape and size; bricks which after being thoroly dry and then immersed in water for 24 hr absorb more than 8% of their volume in water may be rejected; any edge of the brick sidewalk not against a curb or building is to be supported by a continuous spruce plank 2 by 8 in, firmly set in the ground on edge, and held in position by spruce stakes 2 by 4 in, of sufficient length to make a firm and lasting support; suitable areas around trees are to be left unpaved, as directed by the Commissioner. After the roadway is laid and rammed as hereinbefore provided, the sidewalk is to be laid. The subgrade for the sidewalks, where the brick sidewalks are to be laid, is to be 8 in below and parallel with the surface of the finished sidewalk, and on this subgrade the foundation is to be made consisting of coarse-screened paving gravel, no stone larger than ¾ in in greatest dimension being used, and this gravel is to be thoroly compacted by rolling or ramming so that it will be 4 in thick when completed. Upon this foundation is to be spread a layer at least 2 in thick of clean, sharp sand, special care being taken to make the surface of the layer parallel with the finished sidewalk, and the layer of sufficient thickness to bring the bricks to the grade and slope required when rammed firm, as hereinafter provided, and on this sand the bricks are to be laid on their widest side, in courses of uniform width and depth, at right angles with the street, or in herring-bone fashion, with close joints, all longitudinal joints broken by a lap of at least 2 in; the bricks are to be then covered with clean, fine, dry sand, screened thru a 20-mesh sieve; and upon the bricks a plank, covering several courses, is to be placed and carefully rammed with a heavy rammer until the bricks reach a firm, unyielding bed and present a surface of the proper grade and slope, and any lack therein is to be corrected by taking up and relaying the bricks; after the ramming, a sufficient amount of fine, dry sand, aforesaid, is to be spread over the surface and thoroly swept or raked so as to fill the joints."

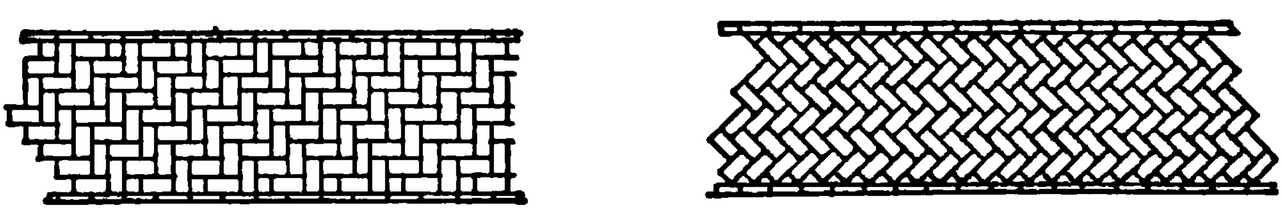

Fig. 4. Brick Sidewalk, Herring-Bone Patterns

Cost Data. Bricks suitable for sidewalks cost from $8 to $10 per M, and will lay flat about 35 to the sq yd. A paver can lay about 75 sq yd

per 8 hr day of square course walk. The cost of a walk as described above is about $0.70 per sq yd divided as follows:

Loading and hauling gravel or cinder base not exceeding 1 mile	$0.06	
Placing and tamping foundation	0.04	
Loading and hauling paving bed not exceeding 1 mile	0.01	
Placing and striking paving bed	0.02	
Laying and ramming brick and spreading sand covering	0.06	
Total cost of labor per sq yd	$0.19	$0.19
35 brick at $10 per M	0.35	
1/6 cu yd cinders at 60 cents	0.10	
1/15 cu yd sand at 90 cents	0.06	
Total cost of material per sq yd	$0.51	0.51
Total cost of labor and material per sq yd		$0.70

For additional cost data, see Table I, Art. 1.

Clay Tile have been used to some extent for sidewalks. The tile are made in square and hexagonal form about 2 in thick and from 8 to 12 in square. The construction of tile walks and method of laying the tile are the same as described for brick walks.

4. Stone Walks

Stone flagging is a very common material for sidewalks on business streets and also on residence streets in those localities where a suitable stone is available. Granite and sandstone are generally used, especially the variety of sandstone known as bluestone. The crystalline varieties of sandstone, such as the Medina and Colorado stone, are also used, tho they are not so suitable as bluestone.

Granite. On account of the cost of dressing, transporting and handling granite, its use has been limited to business streets of heavy traffic, or where large blocks are required to span vaults under the walk. Reinforced concrete has very largely taken its place for this latter class of work. Granite slabs, while practically indestructible, require occasional roughening to prevent the surface from wearing slippery. The slabs are usually from 4 to 6 in thick, and of widely varying sizes.

Bluestone makes an excellent sidewalk paving material. It splits readily into flags of the desired thickness, with even faces, requiring but little dressing. It is compact in texture, hard enough to withstand abrasion, and wears fairly smooth without becoming slippery. Bluestone flags should be from 10 to 20 sq ft in area and from 2 to 4 in thick. They should be laid in a bed of sand about 3 in thick overlying a foundation of gravel or cinders similar to that for brick walks. When the subgrade is of suitable material and well drained, the foundation may be omitted. The edges should be cut straight and square and smooth enough to lay thin joints. The stones should be laid with their length across the walk and should break joints longitudinally. The joints should be closed with a lean cement mortar.

Pittsburgh Specifications for Flagstone Walks are, in part, as follows:

"Flagstone sidewalks shall consist of a gravel or cinder foundation 4 in in depth, a sand cushion 3 in in depth and a flagstone wearing surface 3 in in thickness, making the total thickness of the completed pavement at least 10 in.

"The Foundation shall be of cinder or gravel, free from foreign matter and must contain sufficient fine material to fill the voids in the coarse material. Where the

sidewalk does not adjoin the curb, cross-drains of broken stone 10 by 12 in in cross-sections shall be provided at intervals of 25 ft, connecting the sidewalk foundation with the broken stone curb drain. The sand cushion shall consist of clean Alleghany River sand.

"Wearing Course. The flagstone shall be of the best quality of gray Cleveland sandstone or stone equal in quality thereto, of uniform color and free from flaws or defects of any kind. Unless otherwise specified the flags shall have a width equal to the width of the pavement, a length of not less than 4 ft and a thickness of at least 3 in. The surface shall be sawed to a plane, free from warps, depressions or projections. The edges shall be pitched to true lines and squared for the full depth of stones. The joints shall be cut to straight surfaces and at right angles with the line and surface of the walk, for the full width and thickness of the stone. The flags shall be set with close joints and with a firm bearing thruout their entire area on the cushion and brought to the required grade and cross-section. Where ordered, the top and edge of the flags shall be trimmed and trued after the flags are laid.

Cost Data. The cost varies within wide limits, depending largely upon the cost of transportation (see Table I, Art. 1). In New York City, flag walks of North River bluestone cost from $1.66 to $2.20 per sq yd laid; and in Boston from $2.50 to $3.00 per sq yd.

Small Stone Blocks as Laid in Germany (28). "The mosaic walks are made from small cut stones of from 1½ to 2½ in surface dimensions, laid in semi-circles on a sand cushion, with a cinder base, and tamped smooth, the joints being filled with sand. By using dark and light colored stones very pretty contrasts are obtained as well as a comfortable walk. This pavement is used very often as a border to concrete plates."

5. Bituminous Walks

Tar Concrete is used to some extent in New England, and for suburban sidewalks in localities where a cheap tar is available. The walk is usually constructed in two courses, a foundation course about 4 in thick of coarse gravel thoroly coated with tar, and a wearing course about 1 in thick composed of a mixture of coarse sand and tar, each course being tamped and rolled as it is laid. An intermediate or binder course of smaller gravel is sometimes used. It is difficult to maintain a satisfactory surface on tar walks and they should be considered only a temporary construction. Their cost is about $0.60 per sq yd (see Table I, Art. 1).

In Newton, Mass., a Three-Course Method is used, the different courses being described as foundation course, binding course, and wearing course. The foundation course is composed of coarse gravel from 2 to 4 in in greatest diameter, thoroly coated with hot tar. The binding course is composed of clean screened gravel not exceeding 1 in in greatest diameter, which is heated and mixed with a hot coal tar composition in an amount of about 1 gal of the tar to 1 cu ft of gravel. The wearing course is composed of screened sharp sand, which is heated and mixed with a coal-tar composition, the mixture consisting of not more than 75% of sand and not less than 25% of the tar, by weight. The surface is laid to a total depth of 3 in. Each course as it is laid is thoroly tamped and rolled. The binding course fills the voids in the foundation course to a large extent. The total thickness of these two courses, after compaction, is not less than 2¼ in. The wearing course, which is ¾ in thick, is laid and rolled in a similar manner. The top surface, which is usually sprinkled with a fine sand or Portland cement, is well rolled.

Characteristics. Tar-concrete sidewalks usually are not slippery. If the tar is of the proper consistency the surface is rather elastic and pleasant to walk upon. The use of a tar not possessing the proper characteristics may result in cracks being formed in the surface in cold weather, with consequent disintegration of the pavement, or in warm weather the tar compound may soften to such an extent that the surface becomes objectionable to walk upon. The surface is easily cleaned when intact and is also one which may be easily repaired. Its low cost has led to its general use in many places, altho at the present time it is being replaced to a considerable extent by cement-concrete.

Asphalt Tile Walks. The manufacture of compressed asphalt tiles was begun about 1886. Substantially the same methods are used as have proved successful in the manufacture of asphalt blocks for street pavements. In the manufacture of asphalt tiles, however, a selected white limestone is used for the mineral aggregate, instead of crushed trap rock, as used in the street blocks. The particles of crushed limestone stand out in marked contrast to the black asphaltic cement, giving the tiles an attractive appearance. As the tiles are intended for use in places subjected to foot traffic only, the limestone rock is abundantly durable for the purpose. The crushed limestone and asphaltic cement are thoroly mixed while hot, and these materials are then pressed into block form, receiving a compression of over 100 tons on each tile. This method produces a tile of great density, free from voids, and non-absorbent. Tiles have been used in private work in a multitude of places and under many varying conditions. The Department of Parks of New York City commenced using tiles in 1888. In Prospect Park alone, about 700 000 sq ft of tile walks were laid between 1888 and 1911.

Dimensions of Tiles and Method of Construction. The tiles are made in the following sizes and shapes: Square tiles 8 by 8 by 2 in deep, hexagonal tiles 8 in on the short diameter by 2 in deep, and small hexagonal tiles 5¼ in on the short diameter by 1 in deep. The large hexagonal and square tiles are usually laid upon a foundation of 6 to 8 in of gravel and sand, with a curbing or border of square tiles set on edge. These tiles have a very large bearing surface and do not require a concrete foundation for stability. The small hexagonal tiles, 1 in in thickness, are designed to be laid on a foundation of 3 in of concrete and ½ in of mortar, or upon a mortar bed spread upon a broken stone or gravel foundation.

Asphalt Mastic. This type of pavement is constructed in France by preparing a mastic from a combination of rock asphalt and a refined asphalt fluxed with an asphaltic base petroleum. Sufficient fluxed asphalt is mixed with the powdered rock asphalt so that the mixture will contain 20% of bitumen. A layer of this mixture, of about 1 in in thickness, is placed on a cement-concrete foundation, which consists of about 4 in of concrete and a layer of cement mortar from ½ to 1 in in thickness. A scattering of gravel is spread on the surface and lightly rolled into the asphalt mastic while the latter is still warm.

Cost. The average cost of this pavement in France is approximately $1 per sq yd. The cost of a similar pavement in England is about $1.40 per sq yd.

Characteristics. Footways constructed with an asphalt mastic have many points of excellence. They are practically non-absorbent, very smooth, without joints, pleasant to walk upon, and easily maintained and repaired. A thickness of mastic of ¾ in will last from 5 to 10 years and sometimes longer on streets where the traffic is not heavy.

Sheet-Asphalt in the form of a thin wearing surface of ordinary asphaltic top mixture on a light concrete base makes an excellent park walk less stiff and formal in appearance than concrete. The base should be about 3 in thick and the wearing surface about ¾ in in thickness.

Lincoln Park Sheet-Asphalt Walks (11). "In Lincoln Park proper there are about 50 000 sq yd of walks built principally of cinders, limestone macadam, and gravel macadam. In 1913, the attention of the commissioners was drawn to the difficulty of keeping these walks in condition for foot travel. In wet weather pools of water would stand in the walks, in dry weather the protruding large stones caused a great deal of discomfiture to the pedestrians, thereby causing many of them to walk on the grass, while in winter the removal of snow was unnecessarily difficult. In deciding upon what methods to use to eliminate the above difficulties the following considerations were borne in mind: (1) Low first cost and low maintenance; (2) the walks should be in harmony with the park surroundings; (3) the utilization of the foundations of the walks as they stood; (4) the walks should be of such a nature as to induce people to use them rather than the grass. With these considerations in view the choice was narrowed down to building Portland cement-concrete walks or resur-

facing with an asphaltic mixture. It was finally decided to build some experimental sections with an asphaltic top. These experiments proved so successful in 1913 that in 1914 enough money was appropriated to cover nearly 40 000 sq yd of walks with an asphaltic wearing surface. About one-third the area, or 13 329 sq yd of walk, were sufficiently compact and rough to pave with a wearing surface only. The balance, or 26 657 sq yd, required a binder and top. The binder used was composed of ½- to ¾-in stone and asphalt. A number of tests showed that the percentage of asphalt used, by weight, was as follows: Minimum 3.85, maximum 5.15, average 4.25%. The binder was laid so that it was ¾-in thick after being rolled with a 5-ton roller. The wearing surface mix consisted of asphalt, limestone screenings, stone dust and bank sand in the following proportions:

Asphalt	10.50%
Passing 200-mesh	12.50%
Passing 80-mesh	18.00%
Passing 40-mesh	36.00%
Passing 10-mesh	13.00%
Retained on 10-mesh	10.00%
	100.00%

"The wearing surface was laid ¾-in thick after being rolled with a 5-ton roller. Immediately after rolling Portland cement was brushed over the surface and then rolled with the 5-ton roller. The cement fills the minute voids in the surface and also improves the appearance of the walks. From the cost report it can be seen that asphalt walks can be laid at approximately 60% of the cost of concrete walks where both binder and top are used, and at about 35% of the cost of concrete where a wearing surface only is used.

	Per Sq Yd
Labor:	
Shaping bed of walk	$0.022
Mixing	0.055
Spreading	0.023
Rolling	0.007
Total	$0.107
Material:	
Asphalt	$0.105
Screenings, limestone	0.028
Stone dust	0.017
Sand, torpedo	0.001
Sand, fine	0.044
Cement	0.001
Coal	0.012
Miscellaneous supplies	0.001
Total	$0.209
Teams:	
Hauling, wearing surface	$0.010
Overhead charges:	
Plant	$0.020
Superintendence	0.004
Total	$0.024
Totals:	
Labor	$0.107
Material	0.209
Teams	0.010
Overhead charges	0.024
Total cost per sq yd	$0.350"

Bituminous Macadam Walks (32). "Stake out the position of the sidewalk and excavate the same 2 in, putting the material removed on both sides so as to act as shoulders; then put into the trench excavated the following: A layer of No. 2 trap rock, stones that pass thru a 2-in ring, to a depth of 3½ in, and roll same until compact; cover this layer of stone with a thin coating of No. 3 trap rock, stones that

pass thru a 1-in ring, and roll again; when this second course has been laid and rolled to grade, pour in a good quality of asphalt binder, while hot, at the rate of about 1 to 1¼ gal per sq yd, and cover immediately with screenings from which all dust has been removed; these screenings should be in size from ¼ to ½ in, and should be spread to a thickness of at least ¾ in and then rolled down as soon as possible. The following day the surface should be swept clear of all loose material and a second light application of binder should be poured over and screenings as above mentioned should be spread evenly over the entire surface so as to completely cover the binder and rolled immediately. The rolling down of these screenings immediately after the application of the asphalt binder is very important; therefore the roller should be in constant attendance during the construction of this description of sidewalk, and after rolling down the macadam portion of walk, should roll down the earth shoulders on each side to a width of about 2 ft. A walk 4 ft wide will require about 6¼ tons of crushed stone if rolled to 3-in thickness or 8¼ tons if rolled to 4-in thickness, and about 67 gal of asphalt, for every 100 ft in length, and the excavation of 2.45 cu yd, if cut to the depth of 2 in as previously described."

6. Cinder Walks

In outlying districts where the amount of foot traffic and the value of adjacent property is such as will not warrant the construction of one of the more expensive types of walk, a cheap and fairly satisfactory temporary walk can be built of cinders. The walk should be from 6 to 12 in thick, depending upon the drainage of the subsoil, and built in layers thoroly wetted and tamped or rolled, the top layer being of fine cinders laid to form a good drainage crown. If old planking is available, it should be used as edging on each side of the walk. When practicable, cinder walks should be so laid as to serve as the foundation for a later and more substantial form of walk. Good cinder walks can be built at a cost of from $0.30 to $0.50 per sq yd.

Chicago Practice (28). "Cinder walk consists of not less than 12 in of cinders, usually deposited in 2 layers between 2 rows of 2 by 6-in hemlock plank or curbs, nailed to split cedar posts set 4 ft apart from centers and driven not less than 15 in into the ground. The top of the curbing is set at the grade at which the walk is to be built, 3 in below cement sidewalk grade, and backfilled with earth. The first layer of about 9 in can be either coarse cinders or slag. The second layer of 3 in should be of finer cinders. After these have been compacted a crown of fine, clean cinders is put on and the entire walk rolled with a roller of not less than 500 lb in weight. Some contractors prefer tamping with a regulation concrete tamper to rolling. These walks are objected to in districts which are built up to any extent on account of the cinders being tracked into the houses, destroying floors, carpets, rugs, etc, and are not recommended for any except vacant or sparsely settled districts.

"The average COST of cinder walks in Chicago from 1901 to 1908, based on the total cost, $2 375 359.10, divided by the total mileage 1312.12, was 34.3 cents per lin ft.

Items	Cents per Sq Yd
9 cu ft or ⅓ cu yd at 50 cents, in place	16.67
Lumber at $17.50 per M. 2 ft	3.50
Stakes at 1 cent per lin ft of material	1.12
Nails	0.10
Waste on materials, 1% of value	0.21
Labor, including excavation	4.50
	26.10
Add for superintendence, office expense and profit 15%	3.91
	30.01"

This includes many walks requiring a fill of 2, 3 and sometimes 4 or 5 ft, and can hardly be taken as a fair average cost for the ordinary cinder walk requiring only 15 in of cinders, including crowning. The following itemized cost per lineal foot based on Chicago conditions and Chicago prices would be more nearly correct. Average depth of cinders 1.2 by 6 ft, or 7.2 cu ft in place. Allow for 20% shrinkage, 7.2 + .8 = 9 cu ft loose."

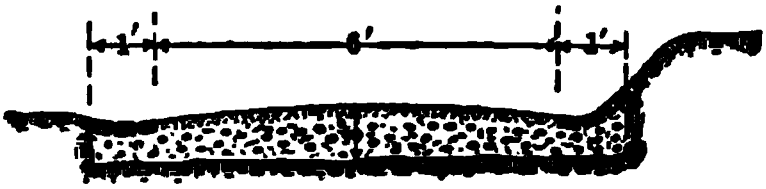

Fig. 5. Gravel Walk with Brick Gutters

7. Miscellaneous Walks

Gravel makes a cheap and satisfactory walk for light traffic, and harmonizes with park treatment better than any other type of walk. The construction should be similar to that of a cinder walk (see Art. 6). The top course of fine gravel should contain sufficient sandy clay or loam to form a compact surface (see Sect. 10). The construction of broken stone walks is similar to that of broken stone roads (see Sect. 11.)

CURBS

8. General Data Relative to Curbs

Curbing of natural or artificial stone is necessary on paved streets and on macadam streets with shallow gutters, to form the back of the gutter, support the sidewalk and protect it from damage by vehicles. The curb must be high enough to prevent water in the gutter from overflowing the sidewalk, without creating an uncomfortable step at street crossings. The height should vary from 5 to 8 in above the gutter, depending somewhat upon the transverse slope of the gutter and the width of the pavement.

Materials and Dimensions. Curbs are usually built of granite, sandstone or cement-concrete. The stones must have sufficient strength and weight to resist the overturning thrust of the sidewalk and sufficient toughness and hardness to withstand the shock and wear of steel tires. They should be from 4 to 8 in wide on top, from 8 to 20 in deep and from 6 to 12 ft in length. The deeper curb is generally used in connection with macadam roadway; the shallow curb with pavements having a concrete base which also forms the base of the curb. Shallow curb is better even for macadam roadways, as it is cheaper, easier to lay and reset and equally as strong as deep curb, if properly laid on the concrete base.

Radius of Corner Curb. Report, Com. Am. Soc. Mun. Imp. (9). Where sidewalks are of sufficient width to permit it, it is recommended that a radius of 12 ft be adopted as a standard corner radius at all corners within 5° of a right angle. At other angles the longest suitable radius should be used by the engineer.

Safety Curbs at Bad Turns (27d). "The principal boulevard entering Huntington Beach, Cal., passes under a railroad, with a bad turn at one end of the underpass. To prevent collisions between vehicles at this point by keeping them on the right side of the road, a double-faced curb has been constructed, 6 in wide on top and 12 in high in the center of the roadway and extending for about 150 ft each side of the subway or underpass. At each end of this curb is a large electric sign warning to 'Keep to the Right.'"

9. Stone Curbs

Granite Curbing should be free from stratification and excess of mica, flint or feldspar. The top and the showing face should be hammer dressed to plane surfaces and as much of the back and of the face below the hammer dressing as is necessary should be pointed to permit of close contact with the sidewalk and gutter respectively. To conform to the slope of the

sidewalk the top should have a bevel toward the face of about ¼ in per ft, with a well defined edge between the face and top. Granite curbs for street and alley returns should be cut in arcs of suitable radii with radial joints.

Cost Data. Granite curbs cost approximately $0.75 per lin ft for 8 by 8-in straight and $1.00 for 8 by 8-in circular; $0.90 for 6 by 20-in straight, and $1.10 for 6 by 20-in circular. See also Table III.

Bluestone Curbs should be from 4 to 6 in in thickness, about 20 in deep and from 6 to 8 ft long, the faces and ends dressed as described for granite curbing. On account of the tendency of this stone to split it can not be cut into arcs, and corners are usually made from other more tractable stone. Curb stones composed of building sandstones are usually sawn on both sides and machine dressed on top with either sharp or rounded edge.

The cost of 6 by 20 in bluestone curb is about $0.50 per lin ft.

Table III.—Character and Cost of Curbs in 1915 in Several Cities

From *Municipal Journal*, Feb. 3, 1916

City	Material	Dimensions in In	Lin Ft	Price per Lin Ft
Oakland, Cal.	Redwood	8 by 12	96 626	$0.11
Oakland, Cal.	Stone	....	2 128	1.48
Denver, Colo.	Cement-concrete	5½ by 30	41 662	0.56
Springfield, Ill.	Cement-concrete	6 by 19	6 942	0.55
Fort Wayne, Ind.	Stone	5 by 18	36 093	0.58
Louisville, Ky.	Limestone	6 by 22	2 818	0.96
New Bedford, Mass.	Granite	6 by 16	21 646	0.91
Saginaw, Mich.	Limestone	4 by 18	21 095	0.55
Butte, Mont.	Cement-concrete	7 by 20	108 600	0.40
East Orange, N. J.	Bluestone	4 by 16	1 665	0.44
Albany, N. Y.	Cement-concrete	7½ by 18	14 424	0.59
Albany, N. Y.	Granite	6 by 12	32 538	0.90
Brooklyn, N. Y.	Cement-concrete	6 by 18	104 100	0.50
Schenectady, N. Y.	Cement-concrete	6 by 18	34 719	0.54
Akron, Ohio	Stone	6 by 18	36 132	0.48
Portland, Ore.	Cement-concrete	6 by 7 by 16	180 084	0.35
Pittsburgh, Pa.	Cement-concrete	6½ by 21	103 467	0.78
Providence, R. I.	Cement-concrete	7 by 18	32 890	0.79
Salt Lake, Utah	Cement-concrete	6 by 16	63 750	0.90
Charleston, W. Va.	Cement-concrete	12 by 24	74 851	0.51

Setting. Shallow curb should be set on a base of lean concrete about 6 in thick laid in a trench dug parallel to the curb line and about 18 in wide. While this base is fresh the stone should be set and adjusted to line and grade by use of heavy wooden mauls. The back of the trench should then be filled with concrete up to the bottom of the sidewalk, the concrete well rammed and covered with earth. In case block gutters are to be laid in front of the curb any portion of the base that would interfere with laying of the block should be removed immediately after the curb is set (see Fig. 1, Art. 2).

Deep Curbs should be set in a trench on a base of broken stone or gravel or other porous material from 4 to 6 in deep. To permit ramming the trench should be about three times the width of the curb. The bottom of the trench should be well consolidated and the base thoroly compacted

by ramming. After the curb is adjusted to line and grade the trench should be filled with the base material placed and tamped in layers to within about 10 in of the top of the stone (see Fig. 2, Art. 3). Where the base material is expensive the backfill is sometimes made with earth. The curb will be much less apt to get out of alignment if the stones are supported at the joints on a bed of concrete extending about 6 in and 12 in up the face and back respectively so as to partially encase the stones at each joint in a small mass of concrete.

STONE BLOCKING or spalls are sometimes used to support the curb, the gravel base being tamped under the curb after it has been set to line and grade on the blocking. While the curb is easier to adjust by this method it is more apt to settle than if laid on a well compacted bed.

The COST of setting 8 by 8-in curb on a 6-in gravel concrete base, including cost of base, is about $0.35 per lin ft; setting 6 by 20 in on gravel base costs about $0.25 per lin ft.

Pittsburgh Specifications for Sandstone Curbs are, in part, as follows:

"**The Curb** shall be of the best quality of Beaver, Baden, or Freeport sandstone, or a sandstone equal in quality thereto, and shall be free from powder cracks, dry and incipient cracks, coal seams, discolorations, and any and all other flaws and imperfections; the color of the stone shall be uniform and subject to the approval of the Director. The finished curb shall not be less than 4 ft long, 2 ft deep and 6 in thick, unless otherwise specified. The top shall be axed to a plane surface, free from all depressions or other irregularities, 6 in in width thruout its full length and the edges cut to true lines. The front of the curb shall be quarry-faced, with 1-in chisel drafts cut along the upper edge and along the joints at right angles to the top. Vertical scores or grooves, spaced 2 to 2½ in between centers, shall be cut in the quarry face with a point, and shall extend 12 in from the top of the curb. They shall be cut straight and true and the bottom of them shall be in the plane of the chiseled drafts. The quarry face shall not in any place project more than ¾ in beyond the plane of the chiseled drafts, nor shall it in any case recede back of said plane. The back shall have a 1-in chisel draft cut along the upper edge and shall be pointed off vertically for 3 in below the top. Joints shall be close and at right angles with the top and face for the full depth and thickness of the stone.

"**Construction.** A trench 18 in in width and 3 ft in depth below curb grade shall be excavated on the curb line and filled with broken stone so as to form a curb drain of the required dimensions. The stone used in the foundation shall be good, clean stone of approved quality, broken to about 3 in sizes. The curb shall be placed on the foundation prepared in accordance with the above directions, each stone being set with a firm bearing thruout its entire length and brought to the established grade and line. The trench at the back of the curb 6 in in width, where there is a sidewalk pavement adjoining, shall be filled with broken stone up to the subgrade of the sidewalk foundation; where there is no sidewalk pavement, the trench at the back of the curb shall be filled within 1 ft of the curb grade. The ditch in front of the curb shall be filled to the subgrade of the roadway pavement with broken stone. The curb shall be backed up to the top with suitable material well rammed, and the placing of broken stone and back-filling shall be done as soon as the curb is set.

"**Where Sidewalks are Disturbed or Damaged** in setting the curb, the Contractor shall repair the same as hereinbelow provided. The loam between the curb and the sidewalk shall be replaced with suitable top soil to a depth of 3 in and the area shall be seeded with a good quality of grass seed. Brick sidewalk pavement shall be relaid for a distance of not to exceed 18 in back from the inner edge of the curb. Flagstone sidewalk pavements extending to the curb shall be removed and recut to fit the curb and then relaid in a workmanlike manner. Concrete sidewalk pavements when damaged or disturbed shall be cut to a true line parallel with the curb and at least 8 in back from the inner edge therefrom and shall be replaced with new work."

Indianapolis, Ind., Specifications for Granite Curbs are as follows:

"All granite curb stone shall be of medium grained granite of even distribution of constituent minerals, uniform in quality and texture, without seams, scales or dis-

colorations, and shall be free from excess of mica or feldspar, and equal in every respect as to the quality of material and dressing to the sample stone in the office of the City Engineer. The minimum length of the curb stone shall be 6 ft except for closures and for corner radial curb where the lengths will be such as are called for on the plans. The depth of the granite curbing shall be 18 in with an allowable variation of not more than 1 in either way. The curb stone shall be uniformly 5 in thick. The top will be dressed with a rise of ¼ in from face to back. The front edge will be dressed to a curve of ½-in radius; the top edge to be pitched to a line parallel to the front edge and shall be dressed to a depth of at least 4 in. The top and the face of the curb for a depth of 12 in shall be smooth pean-hammer dressed without holes or other imperfections. The ends shall be squared so as to afford close joints not to exceed ¼ in for a distance of 12 in down the top."

10. Cement-Concrete Curbs

Proportions and Dimensions. Cement-concrete curbs are usually built in place as two-course work, comprising a core or backing of concrete and a mortar face and top. The proportions of the materials used in the concrete and mortar are the same as for cement walks. Reinforced or armored curb is a form of cement curb in which the edge between the top and face is formed by a metal strip which is set in place while the concrete is being laid and is held in position by lugs imbedded in the concrete. Cement curbs are usually about 6 in wide on top, from 20 to 24 in deep, and divided by suitably constructed joints into uniform lengths of from 6 to 10 ft.

Construction. The curb should be laid in a trench on a base of well compacted gravel, cinders or sand of the same character as the base for stone curbs. If wooden forms are used, they should be of 2-in plank rigidly fastened to stakes so that no displacement can take place during the work of construction. Where much work is being done metal forms will be found advantageous. There are a number of commercial forms on the market which can be had in any desired cross-section. They can be quickly set up and removed, require less skilled labor than wooden forms, and can be used many times over. The back form should first be set up, then the front form to the point where the mortar facing begins. The front form should be given a slight batter to prevent wagon tires from striking the edge. Curb lengths should be formed by inserting metal templates about $^3/_{16}$ in thick at uniform intervals of from 6 to 10 ft. These templates should be withdrawn after the concrete has attained its initial set, leaving the necessary expansion joints. The lower part of the form should be filled with fairly dry cement and tamped up to the point where the mortar facing is to begin. The upper face form is then set up, and plastered with a coating of stiff mortar 1 in thick and the concrete immediately deposited behind it. After this concrete has been rammed the mortar should be carried over the top and floated, and the edge rounded. The upper face form should be removed as soon as possible and the face and top again floated, trowelled and finished with trowel or brush finish, preferably the latter. After the concrete has set sufficiently the lower forms should be removed and templates withdrawn. The latter should be given a thin coating of oil or axle grease to facilitate removal without causing the mortar to flake off. Satisfactory curb has been built in one course, using a slightly richer concrete. While the work is simplified by the omission of the mortar facing, the difficulty of spacing the narrow forms so as to get a uniform surface has prevented the general adoption of this method.

Expansion Joints. The joints between curb lengths will usually take care of expansion. Where the curb is exposed to wide range of temperature,

however, it is well to form additional joints by the use of 1-in planking at intervals of 100 to 150 ft.

Pittsburgh Specifications for Protected Cement-Concrete Curb are, in part, as follows:

"The protected concrete curb may be built at the option of the contractor, either in place, or cast or molded at a point removed from the work.

"**Materials for Concrete Masonry** (see Art. 2, SPECIFICATIONS).

"**The Curb When Built in Place,** shall be constructed in sections between 20 and 30 ft in length. The curbs when so constructed shall be marked off to conform to the scoring of the sidewalk slabs, and sand joints shall be provided between sections as hereinbelow required. When made in the shop, the length of sections shall be 6 ft, except when closures are required. Closures shall be made in strict conformance with the orders of the Director given in the field and the insertion of sections of curb less than 3 ft in length shall not be permitted. The joints between sections of curb built in place shall not exceed ½ in in thickness and shall be made by inserting cross-forms composed of several thicknesses of sheet metal, which shall be carefully withdrawn when the concrete has sufficiently set. The cross-forms shall be drawn before the concrete has sufficiently set to prevent the proper tooling of the edges. The joints shall be carefully filled with dry sand poured into the joint with proper appliances. The exposed surface shall be built to the required grades and shapes by screeding, floating and troweling. The wearing surface shall be formed without the addition of mortar plaster and shall be made by flushing sufficient mortar to the surface by tamping and then finishing as above required. The exposed surface of the work adjoining the forms shall be carefully spaded. No plastering will be permitted. Expansion joints ½ in in thickness shall be provided at each curb return. This expansion joint shall be made by inserting sufficient tar paper to give the required thickness of joint. When completed, the work shall be kept moist for 4 days and protected from traffic and the elements for at least 10 days.

Fig. 6. Cement-Concrete Curb and Granite Block Gutter on Gravel Base

"**The Protected Concrete Curb Not Built in Place,** but cast or moulded in the shop, shall conform to the requirements above specified. The sections shall be cast in rigid forms and shall be allowed to harden for at least 20 days before being transported for placing in the work. They shall be handled, transported and placed with great care and any section that has become spalled or damaged in any manner shall be rejected. Plastering of damaged sections shall not be allowed. The curb blocks shall be set with a firm bearing upon the broken stone foundation herein provided for, and shall be brought to the required line and grade. The joints shall be close and at right angles with the top and face for the full depth and thickness of the curb.

"**The Structural Steel Section** used in the protected curb shall be medium open hearth steel conforming to requirements. Where curb is built in place, the sections of steel protection shall not be less than 10 ft in length and shall be perfectly true to line. When placing concrete, the steel section and anchorage bars shall be rigidly held. A neat joint shall be made between the steel section and the exposed surface of the concrete and the formation of a feather edge will not be allowed. The steel angle used for the curb protection shall be 3 by 2 by ¼ in. Anchorage bars shall be securely riveted with countersunk rivets to the structural sections."

11. Combination Cement-Concrete Curb and Gutter

The combination concrete curb and gutter, on account of its cheapness and neat appearance, is much used on residential streets. The method of construction is similar to that for curb. The concrete base and mortar topping of the gutter are laid, after which the face form of the curb is set and the curb built. The angle between the curb and the gutter should be

rounded to about a 1-in radius. The desired color should be obtained by use of a mixture of sand and lamp black as in sidewalk work. When the curb is built at the same time as the sidewalk, an expansion joint should be left between them. It is advisable to protect the edge of the curb at street corners by some type of armored construction.

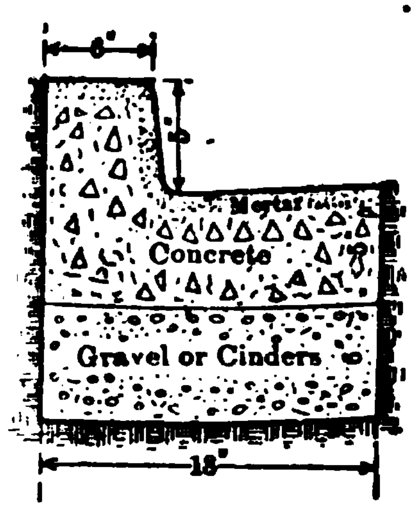

Fig. 7. Combined Cement-Concrete Curb and Gutter

Cost Data. The cost of 1 : 2 : 5 gravel concrete curb and gutter 6 by 8 by 20 in, on a 6-in cinder base, exclusive of cost of forms is between 30 and 40 cents per lin ft. The cost of the labor alone is about $0.11. The combined curb and gutter of Fig. 7 costs from $0.40 to $0.60 per ft, the labor cost averaging about $0.13 per ft.

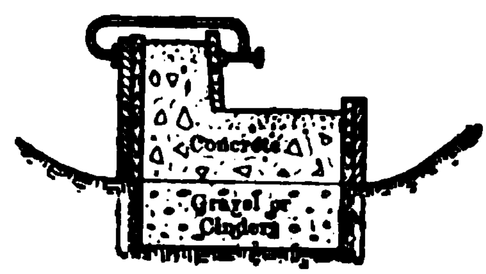

Fig. 8. Wooden Forms for Cement-Concrete Curb and Gutter

Detail Costs to the contractor in Webb City, Mo. (29), of constructing a combined cement-concrete 9 by 6 in curb and 24 in gutter: Concrete for curb and gutter was composed of 1 part of Portland cement to 2 parts of sand to 4 parts of crushed stone. The finish on curb and gutter was 1 in in thickness and was composed of 1 part of Portland cement to 1 part of river sand.

Labor and Materials for 2900 Lin Ft

	Cost per Lin Ft
Labor:	
1 foreman, 99 hr at $0.666	$0.0227
2 finishers, 95 hr at $0.30, 14 hr at $0.50	0.0128
2 form setters, 198 hr at $0.2333	0.0159
2 mixing and placing mortar, 198 hr at $0.233	0.0159
5 mixer men, 464 hr at $0.222	0.0356
Total for labor	$0.1024
Material:	
Cement, mortar and concrete, 1291 sacks at $0.40	$0.1767
Sand, mortar, 457 ½ cu ft at $0.07	0.0116
Gravel, concrete, 122 cu yd at $0.50	0.0210
Gravel, sub-base, 161.1 cu yd at $0.50	0.0278
Total for material	$0.2371
Total for labor and material	$0.3395

GUTTERS

12. General Data Relative to Gutters

Paved Gutters should be provided for roads on steep grades or on fills where there is danger of washouts, as well as for city and suburban streets. On streets provided with a curb, the gutter should have a shallow cross-section similar to that of the roadway, the curb being utilized to form the back of the gutter.

Where No Curb Exists the gutter is usually built of circular section or in the form of a flat V, with the steep side next to the walk. On most paved streets the portion of the pavement adjacent to the curb forms the gutter. With asphalt and macadam pavements, the gutter is usually built of vitrified brick, stone-block or cement-concrete; in the case of sheet-asphalt, to prevent its deterioration from standing water; and in the

case of macadam, to prevent wash. Brick gutters are desirable on a sheet-asphalt street, whether absolutely essential to prevent deterioration or not, as they add materially to the finished appearance of the pavement.

Where a Curb is Used, the gutter should not be so deep as to make an inconvenient step for pedestrians, nor so shallow as to be liable to overflow. Depths of from 5 to 8 in will generally be found sufficient. The longitudinal grade is usually parallel to the curb, tho on very flat grades, the gutter is sometimes given an increased slope toward the catch basin.

Flat Gutters are usually built of cement-concrete, vitrified brick or stone-block, tho flag-stones are sometimes used for this purpose. Concrete gutters are practically always constructed in combination with curbing as described in Art. 11.

Table IV.—Character and Cost of Gutters in 1915 in Several Cities

From *Municipal Journal*, Feb. 3, 1916

City	Material	Width in In	Sq Yd	Lin Ft	Price per Sq Yd or Lin Ft as Indicated
Oakland Cal.	Cement-concrete	..	50 000	.....	$1.20
Santa Barbara, Cal.	Sandstone	..	1 200	.....	1.98
New Britain, Conn.	Cobble	30	164	.....	0.44
New Albany, Ind.	Brick	26	2 612	.....	1.72
Cedar Rapids, Ia.	Cement-concrete	18	.....	8 000	0.35
Haverhill, Mass.	Cobble	..	2 386	.....	0.40
Worcester, Mass.	Granite	..	6 801	.....	1.03
Grand Rapids, Mich.	Brick	..	6 581	.....	1.16
Jefferson, Mo.	Cement-concrete	24	.....	33 421	0.37
West Orange, N. J.	Blocks	..	2 800	.....	1.75
Richmond, N. Y.	Brick	36	1 626	.....	1.67
Greensboro, N. C.	Cement-concrete	30	6 000	.....	0.36
Akron, Ohio	Cement-concrete	6 by 12 by 24	.....	4 551	0.43
Pulaski, Va.	Cement-concrete	18	.....	40 000	0.45
Appleton, Wis.	Cement-concrete	24	.....	19 000	0.50

13. Brick Gutters

Construction. Brick gutters should be constructed of good quality vitrified paving bricks on a concrete base. The bricks should be laid on a paving bed about ½ in thick, composed of a 1 : 4 mixture of dry cement and sand, with lengths at right angles to the direction of the street and breaking joints longitudinally. The joint between the gutter and roadway pavement should be continuous. The type of construction in which the outer edge of the gutter is left with alternately projecting bricks to tooth into the pavement has not proved satisfactory owing to the difficulty of consolidating the paving material between the projecting bricks. Narrow gutters are to be preferred to wide gutters since the joint in the former case is less exposed to the action of passing traffic. The bricks should be rammed in the same manner as a brick sidewalk and then thoroly grouted with a thin grout of neat cement. Brick gutters are usually made from 14 to 27 in wide. An 18-in vitrified brick gutter on a 6-in concrete base, costs about $2.25 per sq yd (see Fig. 1, Art. 2). See also Table IV, Art. 12.

Spokane, Wash., Specifications are, in part, as follows:

"**Bricks.** Where shown on the plans, brick gutters shall be constructed next to and adjoining the curb. The brick used in the gutters shall be what are termed Class..... in the following specifications. All brick shall have the following dimensions: 2⅝ by 4⅛ by 8⅜ in and shall not vary from these dimensions more than 5%. In place of brick of the above dimensions there may be used vitrified blocks 3¼ by 4⅛ by 8⅜ in. When broken, the brick or blocks shall show a dense, stone-like body, uniform in color inside, free from lime, air pockets, cracks or marked laminations. Kiln marks must not exceed 3/16 in and one edge at least to show but slight kiln marks. All bricks or blocks so distorted by burning, as to lay unevenly in the pavement, shall be rejected.

"**Tests.** The absorption of moisture of any brick or portion thereof shall not exceed 3% of the weight of any sample after thoro drying and immersion in water for 3 consecutive days. All bricks or blocks shall be subject to inspection before and after laying and rolling. Brick or blocks to be accepted as Class 1 must not lose more than 20% of their weight after being subjected to the rattler test as hereinafter set out. All brick or blocks to be accepted as Class 2 must not lose more than 35% of their weight after being subjected to the same test.

"**Method of Laying.** On the concrete foundation heretofore laid shall be spread a layer of cement mortar mixed dry and composed of 1 part cement and 3 parts sand not less than 1 in thick, in which the gutter brick or blocks shall be thoroly and firmly bedded. The brick or blocks shall be laid on edge, close together, in straight lines, and with their length parallel to the curbs. The joints shall be broken by a lap of not less than 3 in. The surface of the brick gutters must be true to crown and grade. After the brick or blocks have been laid, the surface shall be swept clean, rolled with a baby steam roller, sprinkled with water, and thereupon the joints and spaces between the bricks or blocks completely filled with cement grout. The grout must be kept continuously stirred while pouring. A second pouring shall be required if in the opinion of the Engineer the first pouring has not completely filled the joints. The cement grouting used shall consist of 1 part cement and 2 parts sand. For a period of 10 days the gutter shall be sprinkled with water if so directed by the City Engineer."

14. Stone Gutters

Granite Block gutters are usually laid on a gravel base about 6 in thick, well compacted and over-laid with sufficient fine bank gravel or sand to form a paving bed for the blocks. After the blocks have been rammed, the joints are filled with firm bank gravel (see Fig. 6, Art. 10). Deep gutters are usually of the type shown in Fig. 9, and are generally constructed with granite block or cobblestone, laid on gravel base. For cost data, see Table IV, Art. 12.

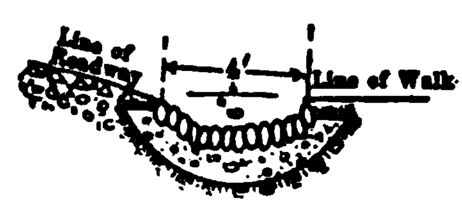

Fig. 9. Barrel Gutter of Cobblestones on Sand Bed and Gravel Base

Los Angeles, Cal., Specifications are as follows:

"**Sand Cushion.** Upon the concrete base laid as above specified and swept free from all dirt and rubbish, shall be spread a layer of sand 2 in in depth. The sand need not necessarily be sharp, but it must be screened, dry and free from more than 3% of loamy matter.

"**Granite Blocks** shall be of sound, durable stone, free from weather marks or seams, and uniform in quality. They shall have dimensions as follows: Length from 8 to 12 in; width from 3½ to 4 in; depth from 6 to 6½ in. They shall be of rectangular form on top and sides, and free from bunches or irregularities which will prevent them from lying closely together. Any blocks having projections or knobs larger than ½ in will be rejected.

"**Laying the Blocks.** Upon the sand cushion shall be set the granite blocks with their longest dimension parallel to the line of the curbs. Each course shall be laid straight and regular with sides perpendicular to the surface and joints broken to the extent of at least 3 in. In no case shall stones of different widths be laid in the same course. All joints shall be close joints, none to exceed ¾ in in width. The blocks must then be thoroly rammed with a rammer weighing not less than 60 lb. Each block must be struck not less than 3 blows and the ramming shall be continued until the

blocks are brought to an unyielding bearing, with a uniform surface, true to line and grade. Any block which, after ramming does not conform to the required surface shall be removed, reset and retamped. No ramming shall be done within 20 ft of the work that is being laid. The joints shall then be filled with a grout made of 1 part of Portland cement and 2 parts of clean, sharp, screened sand. The sand and cement shall be mixed dry until the mixture is of uniform color. Water shall then be added until the mass is of the consistency of thin cream. It shall then be applied to the surface by means of scoop shovels and shall be thoroly swept into the joints until all interstices are filled and the gutter has a smooth and uniform surface. The blocks shall be well sprinkled before grouting. The entire surface of the gutter shall be kept damp for 10 days and no traffic shall be allowed before the expiration of this time."

Cobble Gutters are the cheapest form of gutters, but require frequent cleaning and weeding. Cobbles suitable for gutters should be from 4 to 6 in long and from 2 to 4 in wide. The cost of cobble gutter shown in Fig. 9 is about $0.40 per sq yd exclusive of the cost of cobblestones. When suitable cobbles can be obtained in connection with the work of grading the road, their cost will average about $0.30 per sq yd, making a total of about $0.70 per sq yd for labor and materials.

R. I. State Board of Public Roads Specifications are, in part, as follows:

"The earth, stone and other materials necessary to be removed shall be taken out for a depth of 10 in below the top of the finished surface. All objectionable or unsuitable material found below that depth, shall be removed and shall be replaced with clean sand or gravel which shall be well compacted by ramming. Upon the subgrade thus formed shall be placed, as a bed for the paving stones, a layer of clean sharp sand of such depth as may be required to bring the work to grade. The stone shall be hard, durable cobble or kidney stones, not less than 4 in nor more than 8 in long and not less than 4 in nor more than 6 in wide. The work shall proceed from the sides of the gutter toward the center, keeping the sides in advance of the center. No stone shall be laid on its longest side. After the stones have been set, all joints and cavities shall be filled with clean, fine sand and then the stones shall be carefully and thoroly rammed until no further settlement occurs. If in ramming, any of the stones do not come to the correct grade, they shall be taken out, reset and again rammed. During the ramming the joints shall be kept full of clean, fine sand."

HIGHWAY SIGNS

15. Distance and Direction Signs

Road Signs giving information which will aid in the safe and convenient operation of vehicles are an important feature of a modern highway. The necessity for properly marking roads designed to carry high speed, thru motor traffic is generally recognized, and the practice of including the erection of such signs in the work of construction of the road itself is becoming more common.

Conditions in United States (17). "The American road system is as yet so imperfectly developed nationally and is so rapidly and constantly changing that no national system of road marking can be adopted until the road system itself has been very much more finally and permanently established. In the United States particularly there are numerous and widely separated important centers from which main routes radiate, which condition precludes at this time any attempt to establish a national numerical or color scheme of distinguishing highways. The scope for consideration therefore narrows down to the determination of a definite marking system for main traveled highways considered singly."

Classification. Road signs are of two general classes, distance and direction signs, and warning signs. Each class of signs should as far as practicable be uniform in size, form, color, height, distance from edge of road and location.

Information as to Distances and Directions is usually combined in a single sign located at cross-roads and forks. Intermediate distance signs,

in the form of mile posts, while not essential are desirable on trunk roads.

Materials. Mile posts should be of stone or concrete. Signs should be of malleable cast iron, cast iron or wood. The cost of iron signs precludes their general use at present. Wooden signs should be made of 1-in material, substantially built and strongly bolted to iron or wooden posts firmly set in the ground. The signs should be set as nearly or practically at a uniform height, about 6 ft, above the surface of the road.

Block Lettering should be used of a color contrasting with the body of the sign. A black inscription on a white ground will make the most legible sign.

Examples of Signs. A form of iron sign successfully used by the Automobile Club of Minneapolis is made of malleable cast iron, 30 in long, 5/8 in thick, each line is 3 in wide with 2-in letters, border and letters raised about 1/8 in. The casting is galvanized, the ground then painted two coats of white, letters, figures and border painted black; and the whole finished with a coat of spar varnish. The sign is bolted to a 2½-in galvanized iron pipe set in a concrete base. The cost of these signs erected is given as about $7. This sign was adopted after it had been found impossible to maintain wooden signs owing to their destruction by hunters. Fig. 10 shows a type of wooden sign recommended by Messrs. Evans and Batchelder. This sign is 36 by 13 by 1 in thick, the size of the letters of the three rows being 4, 3 and 2 in respectively.

Evans and Batchelder Report to 3rd Int. Road Cong., 1913 (17).

"STONE SIGNS. American state roads should have well designed mile stones at least, and preferably ½ and ¼ mile stones. Sizes and forms should be absolutely uniform, for each type, and in all states. The face of mile stones should bear the names of the principal terminal points of that road section, in each direction, and numbers giving the distance in round miles under each name to these points. On the side of the stone towards the approaching traveler should appear the name of the next settlement in that direction, with a number giving the round miles distant; and on the other side of the stone visible after passing should appear the name of the last settlement in the reverse direction with a number giving the round miles distant. The ½ and ¼ mile stones, if used, need only be marked with ½ or ¼ or not at all. The precise size and form of stone posts together with the lettering thereon should be absolutely determined by careful engineering design, and the same type of post with its appropriate lettering should be absolutely maintained thruout the country. The lettering should be reduced to a minimum, should be plain, large as possible and of such formation as to be as durable as possible; and a uniform principle of location along the roadside should be rigidly adhered to.

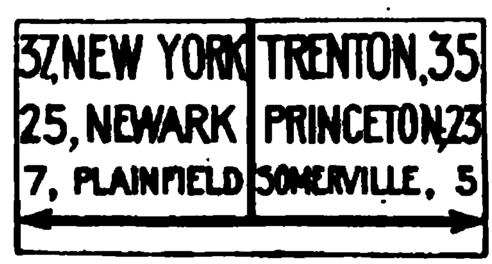

Fig. 10. Wooden Road Sign

"ELEVATED SIGNS. These naturally divide themselves into, (1) distance and direction signs; (2) police and warning signs; (3) warning symbols. Each class of these elevated signs should be as far as possible absolutely uniform in size, form, color, and regular height, distance from edge of road, and location with respect to the physical road peculiarity which it purports to interpret. These factors are all very largely controllable, and merely require rigid adherence to a definite, fore-ordained system of design, construction and location by all authorities touching them. In general, signs should be strictly limited in number of classes. Too few classes do not give adequate information and too many are confusing. The organic law should adequately protect all permissible signs, and should rigidly exclude those of an advertising nature from the highway. The higher the speed of a passing vehicle, especially under conditions of poor light, the more necessity there is for a uniform and simple sign system. Therefore, there should be as few classes as possible; with a uniform size assigned for each class; with a regulated system of plain block lettering showing the relative importance of points visibly by the difference in the size of letters all with a uniform, simple, obvious, visible, and highly contrasting color scheme, and uniform as to location in

relation to the highway points described; and uniform as to height above the road and the distance from the road, as far as possible for the respective classes of signs. As to material, cast iron signs on suitable iron posts are admittedly the best, but few countries can afford the expense involved. For American use, therefore, clear white pine, a very durable wood in form and substance, seems the best, 1 in thick, strongly cleated together, heavily riveted, the body well painted white, the information well painted in black. These signs should be bolted strongly to suitable wooden posts well set in the ground. All signs on posts should be 6 ft on the average above the road surface. Signs on houses or other supports should not be over 9 ft above the road surface. Signs at a uniform height above the road for each class are much more easily read at speed, as any observer on a railroad train will notice when passing a series of well designed stations. If a sign of a certain class is 15 ft high on a wall or building at one point and 4 ft high on a fence at another, with varying distances for others, the eye of the traveler wastes time in locating the sign instead of having all the time available for reading the sign, which should be definitely anticipated at a uniform height above and distance from and location alongside the highway. The same considerations demand as nearly as possible a uniform distance from the highway and a uniform relation to road vagaries. For instance, at cross-roads, a descriptive sign should always be at a uniform location; and a warning sign of a steam railroad crossing or other obstacle or danger should always be a uniform distance back of the obstacle warned.

"DETAILS OF DISTANCE AND DIRECTION SIGNS. Double distance and direction signs should be 36 in long by 17 in deep if carrying three rows of names and mileages, with a fourth row giving authority or the club name responsible for the sign; and 36 in long by 15 in deep if without the fourth line. All letters and numbers must be of the plainest and most obvious block type, the largest or most important row of letters being 4 in deep; the second, reading down, 3 in deep; the third 2 in deep, and the club or location authority 1 in deep. These letter and number sizes, while sufficiently clear and obvious, do not make the sign unduly large or costly. Single distance and direction signs should be 20 in long by 17 in deep, if with the fourth row of lettering, or 15 in deep, without the fourth row of lettering. Single direction signs should be 6 in by 21 in for use in addition to all other signs for constant duplication along the highway where a road section happens to be obscure or tangled."

Wallis Report on Color, Sidewalk Signs and Illumination of Signs (34).

"COLOR. Maximum legibility requires strongly contrasting color combinations. Black letters on a white background are common, but more popular at present is a white letter on a ground of royal or ultramarine blue, most of the enameled iron signs being in these colors. The latter combination is more attractive in appearance than black and white and is very legible by day or night. Silver gray or aluminum on black is particularly effective, especially after dark. Gilt or gold-leaf letters on black used on wooden signs in Boston are dignified and effective. Red is seldom used, altho Washington, D. C., uses clear glass letters blown in a ruby glass plate, and in several northern New Jersey towns ruby letters are blown in a clear glass background. Washington also uses a cast aluminum sign painted slate-gray with letters outlined in gold leaf. Aluminum letters on black enameled steel are used in Rochester, N. Y., and zinc on black lacquered plates in Fall River, Mass. San Francisco used white letters on brown-enameled plates. Aluminum bronze letters on a green background are used in Minneapolis.

"SIDEWALK SIGNS. Several cities have placed street names on sidewalks near the curb at the intersection, on the top or face of the curb, and on gutter plates. These can not be read from cars or other vehicles, where there are many pedestrians, or when there is snow on the sidewalks. In some cities brass or cast iron name plates are set in the sidewalk flush with the surface; in others, tile or composition letters of contrasting color are set into the concrete when it is laid, or the letters are stamped into the green concrete with brass dies. Fremont, Neb., uses cast iron gutter plates with the name cast in the surface. A few cities paint the name on the face of the curb.

"ILLUMINATION AT NIGHT. This has been effected by using transparent, translucent, or perforated signs of various types, supported in metal frames or brackets around street lamps. With cluster incandescent electroliers the signs are usually placed around the central globe. An inexpensive and fairly common practice is to paint the street names directly on the face of the globe. In some cases the name is blown into the glass. On the more important corners of Washington, D. C., a lantern is

used with sides of ground glass on which the name is painted in black, inside which a small gas or electric lamp is placed."

16. Warning Signs

Warning Signs or Symbols should be used to give notice of sharp turns, grades, road and railroad crossings or other physical features of the road which call for the exercise of additional care, as well as to give information of special speed or police regulations. While a very great variety of design and types of danger, precautionary and police signs exists, it is recognized that they should conform as far as practicable to the following requirements: They should be conspicuous and easily and quickly read, and therefore concise; should specify the character of danger to be guarded against and should be located at such a distance from the danger point as to give ample time to be acted upon.

At Railroad Grade Crossings dependence should not be placed solely on the railroad danger sign located on the right-of-way, but additional signs should be erected several hundred feet distant from the crossing. An excellent system of grade crossing signs is used in one state having a number of improved roads crossing a trunk line carrying frequent express service; a sign is placed 500 feet from the crossing with the legend " Railroad Crossing 500 Feet." Two hundred and fifty feet beyond is a second sign reading " Railroad Crossing 250 Feet" and, where power is available, this sign is lighted by several incandescent lamps.

The Inscription should be conspicuous and brief. Letters from 6 to 8 in in height should be employed. The following are some of the forms of inscription commonly used: Danger; Danger Sharp Curve; Slow; Slow Down; Sharp Curve.

Forms of Warning Symbols Adopted by the International Road Congress, which embodies all the essential features of a good sign are shown in Figs. 11, 12, 13, 14 and 15. The standard sign is 18 by 24 in, painted black with white

Fig. 11. Cross Roads

Fig. 12. Turn to the Right

Fig. 13. Turn to the Left

Fig. 14. Dangerous Descent

Fig. 15. Railroad Crossing

symbols. If desired, the name of the club erecting the sign can be painted in black on a yellow band across the top of the sign. These signs cost about $0.50, exclusive of the cost of erection.

Traffic Regulation Signs should be erected on the main highways entering a city. Speed zones within the city and individual streets for which special regulations are applicable should also be marked. A speed sign should have the maximum permissible speed in conspicuous letters, with the town or zone limits and the authority for the ordinance in a smaller inscription. On city streets the signs should be located at the curb, about 8 ft above the sidewalk and as small as practicable, consistent with conspicuousness and legibility.

Use of Portable Traffic Signs (18). **"Many municipalities, both large and small, are using fixed or portable signs for several purposes connected with traffic control, the more common being to prevent cutting of corners at street intersections; to regulate the parking of vehicles; and to give warning of dangerous conditions.**

"Traffic signs should be uniform in SHAPE AND SIZE and carry the least amount of

wording which will make the meaning plain. Circular disks from 12 to 18 in in diameter are becoming common, as they are readily distinguished from the advertising signs which are so frequently seen on streets and highways. To be of service, the sign must attract attention and for this reason strongly contrastihg COLORS are used. Red, as the universal danger or warning color, is the one most commonly used, the lettering ordinarily being in white or aluminum letters on a red background, in order that the red may predominate and cause the light color to show plainly on the dark background. Other combinations used are black and white, black and aluminum, and blue and white.

"PORTABLE STANDARDS are usually about 5 ft high and made so that the instructions 'Drive to the Right,' or some similar notice is visible from each of the four directions of approach. They should be so constructed that they will not be damaged when tipped over. If they are to be left in place at night, they should be fitted to hold a lamp or lantern, unless they are well lighted by nearby street lamps.

"Many municipalities find it necessary to restrict the PARKING of vehicles in certain districts to prevent the blocking of streets and interference with business. Some prohibit parking in front of hotels, theaters and other places where a large number of patrons arrive or leave by motor vehicles. Others set aside whole blocks where vehicles are not allowed to stand, and some allow parking in the center of the street or on one side only. On account of this lack of uniformity in different localities, areas in which parking is restricted or prohibited should be plainly marked.

"For WARNING OR CAUTION SIGNS marking danger points, bright red disks 18 in in diameter on permanent posts or standards outside of the traveled portion of the street are very effective. Signs smaller than 18 in should not be used, as they could not then be read or would not sufficiently attract attention at a considerable distance. Warning signs should be 7 or 8 ft high, and placed 50 to 75 ft from the point of danger."

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SECTION 26

HIGHWAY BRIDGES, CULVERTS, RETAINING WALLS, FOUNDATIONS AND GUARD RAILS

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HIGHWAY BRIDGES

CULVERTS**

RETAINING WALLS**

FOUNDATIONS**

GUARD RAILS**

HIGHWAY BRIDGES

1. Location and Waterway for Highway Bridges

Preliminary Investigations. The great majority of highway bridges are built across rivers and streams, altho it oftentimes happens that a highway must be conducted over a railroad right-of-way, and sometimes over another highway which is at a different level. Special local conditions

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may influence the location. If the river is navigable, Government regulations must be met. If the bridge is to connect a highway in a thickly settled community, its location will be practically determined. If it is a country bridge, oftentimes the highway approaches may be changed to allow the most economical location. In deciding upon the site, it is usually necessary to make a contour survey of one or more locations. Such a survey should show enough topography so that a careful study may be made in the office of existing conditions, and should include soundings of the river-bed, together with as much data as possible regarding its composition. It is oftentimes necessary to make borings to determine the character of the subsoil and to locate a suitable foundation for piers and abutments. The elevation of high and low water, as well as an average high stage, should be determined, together with some idea of the frequency of occurrence. In addition, it is well to have information regarding the velocity and set of the current. After the definite site has been decided upon, it is necessary to make an accurate location of the center line of the bridge in order to obtain its true length and definitely locate piers and abutments. This is usually done by triangulation, and consists of measuring the distance between two points, one on each side of the river, by laying off a carefully measured base from one of these points along the shore or bank of the river, and measuring the angles formed at each end of the base by lines to the point on the other side of the river. The degree of precision necessary in measuring the base will depend upon existing conditions, and may range from the use of a standard 300-ft steel tape, making corrections for temperature, grade, etc, to the use of an ordinary 100-ft steel tape. The course should be measured several times and a mean result obtained. For refined methods see Sect. 5, Arts. 6 and 35 (4), (14) and (17). The ordinary case for highway bridges usually will be satisfied by careful work with a 100-ft steel tape used on the base, and for the angles by the use of a properly adjusted transit which reads to single minutes, provided each angle is repeated, first to the right and then to the left, and a mean value taken. With these two angles and the included side, the distance between the two sides of the river may be determined by trigonometry.

The Waterway beneath the bridge depends upon the amount of congestion caused by piers and abutments. The channel must not be unduly obstructed, so that in time of freshet the structure will not be endangered by the ice, swirls and eddies causing washouts, and floating logs and débris. The chief point to be determined is the rise in water level which occurs just up stream from the piers, the rise at the piers being less than this amount. The average case may require no mathematical investigation, the judgment of the engineer being used to obtain a proper elevation of the bridge above high water. In cases where the depth in proportion to the width is considerable, or where the river is spanned by a number of plate girders or arches, the following formula by Merriman (16a) may be used. In extreme cases, the problem may become more complicated, requiring a more careful study by the principles of hydraulics. In any case, such solutions are apt to be more or less approximate, and the judgment of the engineer must be taken into consideration.

$$C\sqrt{2g}\ \left[\tfrac{2}{3} B\ (H+h)^{\frac{3}{2}} + b\, D\, (H+h)^{\frac{1}{2}} \right] = q$$

B = original width, b = contracted width, D = depth of water before congesting the opening, H = rise in water level, q = discharge of stream in cu ft per sec, h = head due to velocity of approach. The coefficient C

may be taken as 0.9 for piers with round ends, and 0.8 for triangular cut-waters. In order to arrive at such determinations, data upon the volume of discharge is necessary.

Discharge Data may come under one of three cases. (1) Records at some gauging station near the location. (2) Records at some point on the same river some distance away, or on a similar river. (3) No records at all. In case 2, find drainage area at site of bridge and consider discharges as being proportional to drainage area. Case 3 will seldom occur where it can not be reduced in some way to case 2. Note that flood measurements of discharge are usually less reliable than medium or low water measurements.

2. Economical Length and Cost of Highway Bridges

Span Length. In determining the number of spans to use, consideration should be given to the principle that the cost of the superstructure should equal the cost of the substructure in order for the total cost to be a minimum. This requires a careful preliminary study, especially where more than one span is necessary, or where it is a question of one long span or two shorter spans. Estimates should be made of the cost of the bridge itself, and of the piers and abutments, for different combinations. The first cost of a bridge is not the only item which should receive consideration in an economical study of the problem. The life of the structure should be considered. Many highway bridges of cheap construction have proved too light and altho stable for a time, they have lacked stiffness when subjected to a moving load and have soon become unfit for use without constant repairs. A properly designed steel highway bridge if kept painted should have a life of at least from 40 to 50 years. Wooden floors must be replaced about every 4 years. Reinforced concrete bridges should last indefinitely.

The Economic Depth and Panel Length of trusses as determined by experience are shown by the following tables as given by Ketchum (15b), in "Structural Engineers' Handbook."

Depths and Panel Lengths of Thru Highway Bridges Used by American Bridge Company

Type of Truss	Span in ft	No. of Panels	Ratio of Depth to Panel Length
Pratt, riveted and pin-connected	80 to 90	5	1.0
	96 to 126	6	1.0
	133 to 147	7	1.0
	152 to 168	8	1.1
Quadrangular, Warren riveted	80 to 90	5	1.0
	90 to 114	6	1.0
	119 to 133	7	1.0
	135 to 152	8	1.1
Camel-back, pin-connected	162 to 180	9	1.0, 1.159, 1.25, 1.29
	190 to 220	10	1.0, 1.238, 1.28, 1.43
Petit, pin-connected	240 to 276	12	1.0, 1.397, 1.555, 1.714
	294 to 322	14	1.0, 1.36, 1.60, 1.84, 2.00

Types of Bridges Adopted in the American Bridge Company's Standards

Pratt, pin-connected trusses	80 to 168 ft span
Pratt, riveted trusses	80 to 168 ft span
Warren, quadrangular, riveted trusses	80 to 152 ft span
Inclined chord Pratt (camel-back) pin-connected trusses	168 to 220 ft span
Petit trusses, pin-connected	220 ft span and over

The Cost of Bridges includes cost of material, fabrication, erection and transportation. The cost of fabrication and erection can not be accurately given but the following figures taken from Ketchum's "Structural Engineers' Handbook" (1914) (15b) may be used as a guide for estimates.

"The cost of material varies with the market and may be found quoted in the various engineering journals.

"The cost of fabrication includes cost of drafting and cost of shop labor. To this should be added cost of mill details for materials ordered directly from the rolling mill which is cut to exact length and punched, such as joists and similar members. The cost of drafting will be from $1 to $2 per ton where sketch details are used, and from $2 to $4 per ton where members are detailed separately. The costs of shop labor may be estimated for the structure as a whole according to the following data, and are exclusive of fence and joists and include detailing and one coat of shop paint. For reaming add 0.15 cents per lb.

Approximate Shop Costs of Pin-Connected Bridges

Bridges weighing 5 000 lb and less	1.30 cents per lb
Bridges weighing 5 000 to 10 000 lb	1.20 cents per lb
Bridges weighing 10 000 to 20 000 lb	1.00 cents per lb
Bridges weighing 20 000 to 40 000 lb	0.90 cents per lb
Bridges weighing 40 000 to 60 000 lb	0.80 cents per lb
Bridges weighing 60 000 to 100 000 lb	0.75 cents per lb
Bridges weighing 100 000 to 150 000 lb	0.70 cents per lb
Bridges weighing 150 000 lb and up	0.65 cents per lb

Approximate Shop Costs of Riveted Truss Bridges

Bridges weighing 5 000 lb. and less	1.15 cents per lb
Bridges weighing 5 000 to 10 000 lb	1.00 cents per lb
Bridges weighing 10 000 to 20 000 lb	0.90 cents per lb
Bridges weighing 20 000 to 40 000 lb	0.85 cents per lb
Bridges weighing 40 000 to 60 000 lb	0.75 cents per lb
Bridges weighing 60 000 to 100 000 lb	0.70 cents per lb
Bridges weighing 100 000 to 150 000 lb	0.65 cents per lb
Bridges weighing 150 000 lb and up	0.60 cents per lb

Approximate Shop Costs of Plate Girder Bridges

Spans weighing 10 000 lb and less	0.90 cents per lb
Spans weighing 10 000 to 20 000 lb	0.85 cents per lb
Spans weighing 20 000 to 40 000 lb	0.75 cents per lb
Spans weighing 40 000 to 60 000 lb	0.70 cents per lb
Spans weighing 60 000 to 100 000 lb	0.60 cents per lb
Spans weighing 100 000 lb and up	0.50 cents per lb

"**Card of Mill Extras.** For cost of fabrication of joists estimate according to the following cost of mill details: If the estimate is to be based on card rates it will be necessary to have the subdivisions a, b, c, d, e, f, r, etc, as follows:

a = 0.15 cents per lb. This covers plain punching one size of hole in web only. Plain punching, one size of hole in one or both flanges.

b = 0.25 cents per lb. This covers plain punching one size of hole either in web and one flange or web and both flanges. The holes in the web and flanges must be of the same size.

c = 0.30 cents per lb. This covers punching of two sizes of holes in web only. Punching of two sizes of holes either in one or both flanges. One size of hole in one flange and another size of hole in the other flange.

d = 0.35 cents per lb. This covers coping, ordinary beveling, riveting or bolting of connection angles and assembling into girders, when the beams forming such girders are held together by separators only.

e = 0.40 cents per lb. This covers punching of one size of hole in the web and another size of hole in the flanges.

f = 0.15 cents per lb. This covers cutting to length with less variation than ± ⅜ in.

r = 0.50 cents per lb. This covers beams with cover plates, shelf angles, and ordinary riveted beam work. If this work consists of bending or any unusual work, the beams should not be included in beam classification.

"Shop Costs of Individual Parts of Bridges. The cost of fabricating joists and other similar members should be estimated on the basis of mill details, which see.

"Eye-Bars. The shop cost of eye-bars varies with the size and length of the bars and the number made alike. The following costs are fair averages: Average shop costs of bars 3 in and less in width and ¾ in and less in thickness are from 1.20 to 1.80 cents per lb, depending upon the length and size. A good order of bars running 2½ in x ¾ to 8 in x ¾ in, and from 16 to 20 ft long, with few variations in size, will cost about 1.20 cents per lb. Large bars in long lengths ordered in large quantities can be fabricated at from 0.55 to 0.75 cents per lb. To get the total cost of eye-bars the cost of bar steel must be added to the shop cost.

"Chords, Posts and Towers. In lots of at least four, the shop cost is about as follows: Members made of two channels and a top cover plate with lacing on the bottom side, or two channels laced on both sides cost about 1.00 to 0.85 cents per lb for pin-connected members weighing from 600 to 1500 lb; and about 0.80 to 0.70 cents per lb for members with riveted end connections. Members made of four angles laced cost from 0.80 to 1.10 cents per lb for members with riveted ends. Members made of two angles battened will cost about 0.50 cents per lb. Angles used without end connections should have their cost estimated on the basis of mill details, which see.

"Pins. The cost of chord pins will vary with the size, number and other requirements. The shop cost of chord pins and nuts may be estimated at from 2 to 3 cents per lb. Rollers will cost practically the same as pins. Rolled rounds (pin rounds) are used for making pins and rollers.

"Latticed Fence. The shop cost of light, simple, latticed fence, made of two 2 in x 2 in angles, with double lacing and about 18 in deep, will be about 2 cents per lb; while the shop cost of latticed fence, with ornamental rosettes or ornamental plates, may be as much as 4 to 5 cents per lb.

"Floor Beams and Stringers. Plate girders used for floor beams and stringers will cost from 0.60 to 1.25 cents per lb, depending upon the weight, details and number made at one time. Floor beams made of rolled I-beams will cost from 0.50 to 0.75 cents per lb.

"The Cost of Erection includes (1) cost of hauling to the site; (2) falsework and placing steel in position; (3) riveting; (4) painting. Hauling may be estimated as about 25 cents per ton mile plus from 25 to 50 cents per ton loading and unloading. Falsework under ordinary conditions will cost \$6 to \$8 per thousand plus the cost of the timber. If piles are to be driven for a foundation, their cost will vary with local conditions. These may be estimated as from 20 to 50 cents per lin ft in place. The cost of placing and bolting is about as follows:

Spans 30 to 60 ft	\$12 to \$15 per ton
Spans 60 to 100 ft	10 to 12 per ton
Spans 100 to 150 ft	9 to 10 per ton
Spans 150 ft and over	8 per ton

"The cost of riveting in pin-connected spans will vary from 7 to 12 cents per rivet while the cost in riveted trusses will be from 6 to 10 cents per rivet. The number of rivets in thru riveted spans will be about 250 to 300 for a four-panel bridge, and 1300 to 1500 for a nine-panel bridge. Pin-connected bridges have about one-third to one-half as many.

"Transportation depends upon freight rates between different points, information regarding which may be obtained from the railroads.

"Cost of Painting. Structural steel should be painted with one coat of linseed oil, linseed oil with lampblack filler, or red lead paint at the shop; and two coats of first-class paint after erection. The two field coats should be of different colors, care being used to see that the first coat is thoroly dry before applying the second coat. Light structural work will average about 250 sq ft and heavy structural work about 150 sq ft of surface per ton of metal, and will take about ½ gal of paint for the first coat and ⅜ gal for the second coat per ton of steel. A good painter should paint 1200 to 1500 sq ft of plate surface or 300 to 500 sq ft of structural steel work in a day of 8 hr. A thick red lead paint mixed with 30 lb of lead to the gallon of oil will take fully twice as long to apply as a graphite paint or linseed oil."

3. Loads for Highway Bridges

Outer and Inner Forces. A bridge must be designed and built to carry the loads which come upon it. The loads bring into action the supports, or reactions, which, together with the loads, are called OUTER FORCES. The outer forces bring into action certain inner, or fiber stresses, called INNER FORCES. A structure is said to be STATICALLY DETERMINED with regard to the outer forces when the reactions may be found by statics. In general, a structure upon two points of support has the points of application of these reactions known. This leaves the magnitude and direction of each reaction unknown. By placing rollers under one support, or in some way arranging a sliding device, this reaction may be assumed to take no horizontal component and thus its direction becomes known, and leaves only three unknown values. Since there are three statical equations of equilibrium, these values may be found. In the case of a bridge with one end on rollers and all the loads vertical, the problem becomes even more simplified.

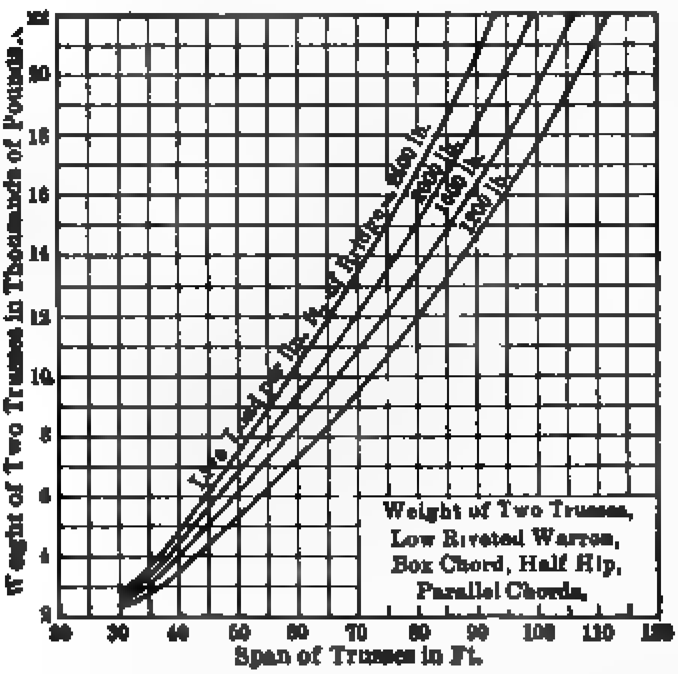


Fig. 1

Loads may be divided into (1) DEAD, (2) LIVE. The dead load is the weight of the bridge. The live load is the load which may be removed from the structure, and may be either fixed or moving, and will vary with the local conditions. It may take the form of a uniformly distributed load such as w lb per lin, or sq ft. It may cover all, or only a portion, of the space. It may also take the form of concentrated loads.

Dead Loads are found by successive approximations; that is, the dead load is assumed, the structure designed, and the weight computed, this computed weight is compared with that assumed and, if found to differ materially, a new weight is taken and the structure redesigned. The weight of a bridge includes (1) weight of metal, and (2) weight of other material, such as flooring. Owing to a greater variation in width of roadway and design in highway bridges than in railroad bridges, formulas will not

Weight of Two Trusses in Thousands of Pounds

Fig. 2

give so close an approximation to the weight of the former as to the weight of the latter.

Figs. 1 to 5, taken from Ketchum's "Design of Highway Bridges" (15a), give the weight of several types of trusses for different span lengths. Fig. 6 gives the weight of lateral bracing, and Fig. 7, the weight of floor beams. In each case, the weight of flooring and stringers must be figured separately and included. By use of these curves, a very fair estimate of dead load may be made.

Fig. 3

Live Loads on a highway bridge may include WEIGHT OF TRAFFIC AND WIND LOAD, IMPACT LOAD, SNOW LOAD, and TEMPERATURE LOADS. The amounts of these loads are given in specifications. The traffic load should be assumed with reference to the location of the bridge, and due regard should be given to future possible conditions. Impact stresses may be treated in one of two ways. The allowable unit stress for live load may be reduced or the live load stress in different members may be increased. This last is obtained by a formula which usually takes the following form.

$$\text{IMPACT} = S\left(\frac{C}{L + C_1}\right)$$

where IMPACT is the impact stress to be added to the live stress, S is the live load stress, L is the length which was loaded to produce the live load stress, and C and C_1 are constants. The weight of SNOW and ICE varies with the latitude and may be taken as 30 lb per sq ft in northern New England, 20 lb per sq ft in latitude of New York City, and 10 lb per sq ft in latitude of Baltimore. The TEMPERATURE LOAD may amount to the reaction multiplied by the coefficient of friction of the rollers. An allowance of 83° C (150° F) requires a space for a motion amounting to ⅛ in for each 10 ft of length. This load is usually negligible in considering stresses in bridge members.

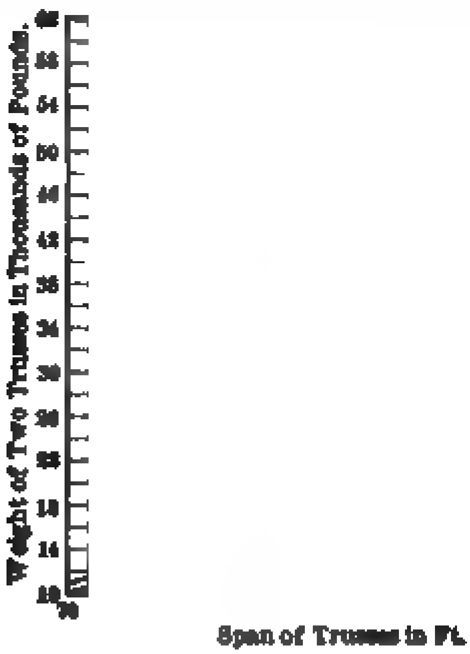


Fig. 4

4. Specifications for Highway Bridges

Specifications for Steel Highway Bridges have been written by various consulting engineers and bridge companies. The following extracts are

taken from the four different specifications given below. The letter after each item shows its source. It should be noted that all except Cooper allow for impact by increasing the live load stresses. Key: C = Cooper, 1909 (Revised by Berger) (8); O = Ostrup, 1911 (19); K = Ketchum, 1914 (15b), M = Mass. R. R. Comm., 1908.

Weight of Two Trusses in Thousands of Pounds.

Span of Trusses in Ft.

Fig. 5

Types. Wooden stringers or rolled beams up to 20 ft, M, O; rolled beams up to 25 ft, C; up to 30 ft, K; rolled beams or plate girders 20 to 30 ft, M; 20 to 40 ft, C, O; plate girders 30 to 70 ft, M; 40 to 70 ft, O; plate or lattice girders 40 to 80 ft, C; plate girders or riveted low trusses 30 to 80 ft, K; 70 to 100 ft, M; 80 to 100 ft, O; lattice girders 80 to 120 ft, C, riveted trusses 100 to 125 ft, M; 100 to 160 ft, O; riveted or pin-connected trusses 125 to 200 ft, M; 80 to 160 ft, K; over 120 ft, C; pin trusses over 160 ft, O, K; over 200 ft, M.

Clearances. Seven feet on each side of track center at heights exceeding 1 ft above top of rail, C, O, K; at heights between 10 in and 12 ft above rail, M; on straight track, and equivalent on curves. Fifteen feet clear above rail, C; same for width of 8 ft above track, M, K; for width 6 ft, O; for country bridges not carrying electric cars 12 ½ ft clear above roadway, C, K, O; for such city bridges 14 ft, O.

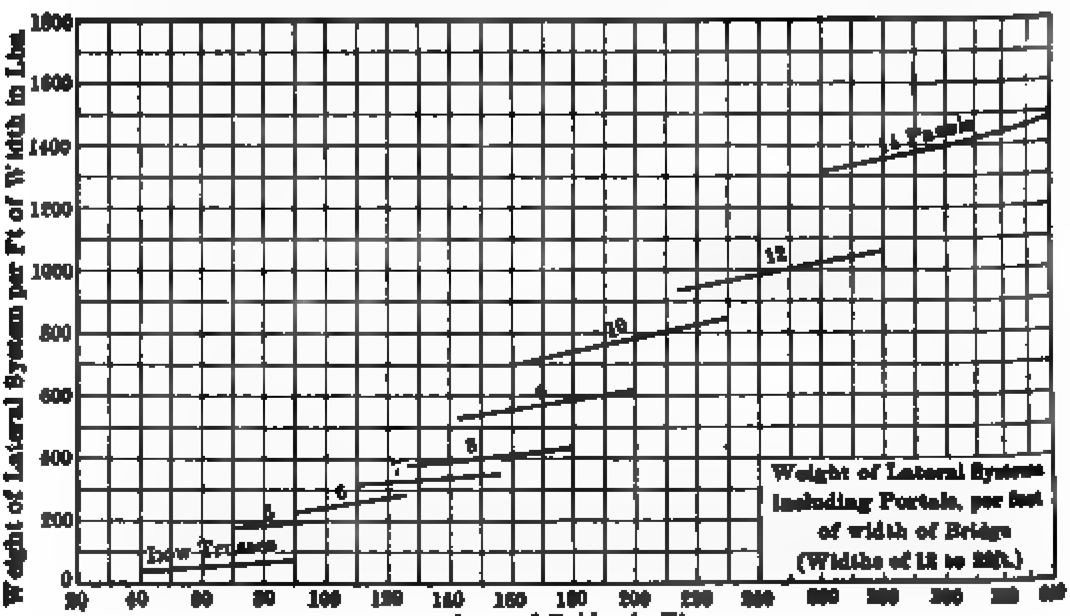


Fig. 6

Classification. COOPER: A_1, city bridges buckle plate floors and paving on concrete base. A_2, city bridges plank flooring: B, suburban or interurban bridges carrying heavy electric cars; C, town or country bridges carrying light cars, or heavy loads from quarries or manufactories; D, country bridges carrying ordinary traffic. MASS. R. R. COMM. AND OSTRUP: A, city bridges subject to heavy loads; B, suburban or

town bridges or heavy country highway bridges; C, light country highway bridges. KETCHUM: A, city traffic; B, suburban or interurban heavy electric cars; C, country, ordinary traffic, light electric cars; D_1, country, heavy traffic; D_2, country, light traffic.

Loads. DEAD. Weight of metal, weight of material other than steel, C, O, K, M; stone blocks 160 lb per cu ft, O, K; paving brick 150 lb per cu ft, O, K; concrete 150 lb per cu ft, K; 130 lb, O; asphalt 130 lb per cu ft, O, K; oak or hardwood 4½ lb per ft, B, M; pine or soft wood 3½ lb, C, O, K; rails, fastenings and splices, etc, 100 lb per lin ft of track, O, K, M; minimum weight of cross-ties and guard rails 200 lb per lin ft of track, O; total weight of floor above stringers not less than 300 lb, M.

LIVE FOR FLOOR SYSTEM. Cooper, classes A_1 and A_2, and Ketchum, class A; a concentrated load of 24 tons on two axles 10 ft center (occupying 12 ft in width for a single line and 22 ft for a double line), and upon the remaining portion of the floor, including footwalks, 100 lb per sq ft. Cooper, class B and Ketchum, class B; a concentrated load of 12 tons on two axles 10 ft center or on each street-car track 24 tons on two axles 10 ft centers, and on remaining portion 100 lb per sq ft. Cooper, class C, and Ketchum, class C; a concentrated load of 12 tons on two axles 10 ft centers, or on street-car track 18 tons on two axles 10 ft centers, and on remaining portion 100 lb per sq ft. Cooper, class D, a load of 80 lb per sq ft total floor surface or 6 tons on two axles 10 ft centers. Ketchum, class D_1; a load of 100 lb per sq ft total floor surface or 20 tons on two axles 11 ft centers and 7 ft gauge, 4/5 of load on rear axles. Ketchum, class D_2; a load of 80 lb per sq ft total floor surface or 15 tons on two axles 10 ft centers and 6 ft gauge, ⅗ load on rear axles. Ostrup; if electric railway tracks occur, a series of 50-ton cars on two trucks 20 ft centers, truck axles 5 ft centers, 5 ft gauge, having total length of 40 ft and width of 10 ft, shall be used in addition to the following: Class A, a load of 20 tons on two axles 8 ft centers, 5 ft gauge, occupying a length of 20 ft and width 10 ft and remaining area 100 lb per sq ft. Ostrup class B; a load of 15 tons on two axles 8 ft centers, 5 ft gauge, remaining area 90 lb per sq ft. Ostrup, class C; a load of 10 tons on two axles 8 ft centers, 5 ft gauge, remaining area 80 lb per sq ft. Mass. R. R. Comm., a 50-ton double-truck car, wheel base 25 ft, wheel base of truck 5 ft, to be used on all classes; also a 15-ton road roller 11 ft center to center of rollers with 6 tons on front and 9 tons on rear and for this condition allowed fiber stresses may be increased 30%. Mass., class A; also 100 lb per sq ft of surface or load 20 tons on two axles 12 ft centers, 6 ft gauge. Mass., class B; also 100 lb per sq ft of surface or load 12 tons on two axles 8 ft centers. Mass., class C, also 80 lb per sq ft of surface.

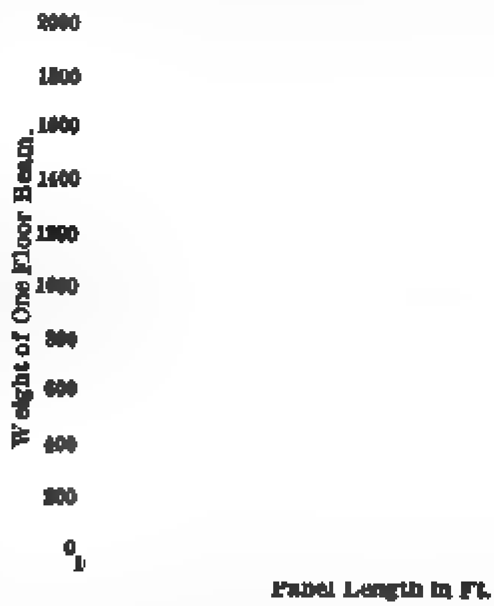


Fig. 7

LIVE FOR TRUSSES. Ostrup, class A: 100 lb per sq ft, spans 100 ft or less; 80 lb, spans 200 ft or over, proportionally for intermediate spans. Class B: 90 lb per sq ft, spans 100 ft or less; 70 lb, spans 200 ft or over. Class C: 80 lb per sq ft, spans 100 ft or less; 60 lb, spans 200 ft or over. In addition to these loadings, a series of cars as afore stated (see FLOOR SYSTEM). Mass. R. R. Comm., class A, same as Ostrup. Class B, same as Ostrup, class C. Class C: 80 lb per sq ft spans 75 ft or less; 50 lb, spans 200 ft or over. In addition to these loadings, a car on each track as stated under floor system, or a uniform load on each track varying from 1500 lb to 1000 lb per lin ft of track.

WIND. 300 lb for each foot of span, 150 lb treated as moving load for top lateral of deck and bottom laterals of thru bridges; 150 lb for each foot span for bottom laterals of deck and top laterals of thru bridges, C, K; in bridges with sway bracing, one-half of wind load assumed to pass to lower chord, K; 50 lb per sq ft exposed

Live Loads for Trusses: Cooper and Ketchum

Span in Ft	Class A		Class B		Class C		Class D_1	Class D_2
	Pounds per Lin Ft of Each Car Track	Pounds per Sq Ft of Remaining Floor Surface	Pounds per Lin Ft of Each Car Track	Pounds per Sq Ft of Remaining Floor Surface	Pounds per Lin Ft of Each Car Track	Pounds per Sq Ft of Remaining Floor Surface	Pounds per Sq Ft of Floor Surface	Pounds per Sq Ft of Floor Surface
Up to 100	1 800	100	1 800	80	1 200	80	80	75
105	1 770	99	1 770	79	1 190	79	79	74
110	1 740	98	1 740	78	1 180	78	78	73
115	1 710	97	1 710	77	1 170	77	77	72
120	1 680	96	1 680	76	1 160	76	76	71
125	1 650	95	1 650	75	1 150	75	75	70
130	1 620	94	1 620	74	1 140	74	74	69
135	1 590	93	1 590	73	1 130	73	73	68
140	1 560	92	1 560	72	1 120	72	72	67
145	1 530	91	1 530	71	1 110	71	71	66
150	1 500	90	1 500	70	1 100	70	70	65
155	1 470	89	1 470	69	1 090	69	69	64
160	1 440	88	1 440	68	1 080	68	68	63
165	1 410	87	1 410	67	1 070	67	67	62
170	1 380	86	1 380	66	1 060	66	66	61
175	1 350	85	1 350	65	1 050	65	65	60
180	1 320	84	1 320	64	1 040	64	64	59
185	1 290	83	1 290	63	1 030	63	63	58
190	1 260	82	1 260	62	1 020	62	62	57
195	1 230	81	1 230	61	1 010	61	61	56
200 and over	1 200	80	1 200	60	1 000	60	60	55

NOTE: Cooper, Class D, same as Ketchum, Class D_2.

surface of both trusses, unloaded, 30 lb per sq ft exposed surface structure, loaded, M, O; area of car to be added to area structure, M; when structure is loaded, in addition, 150 lb per lin ft of loaded chord, or 300 lb per lin ft, if carrying electric cars. Minimum 250 lb per lin ft for loaded and 150 lb per lin ft for unloaded chord, O. Centrifugal and longitudinal forces provided for in all.

IMPACT. Allowance in unit stress, C; $I = S \times 100/(L + 300)$, K; same for highway traffic only, O; $I = S \times 200\ /(L + 300)$ bridges carrying electric railways, O; I = impact, S = computed live load, L = loaded length in feet. The following percentages of live load are given by M: Floor beams and stringers, 25; floor beams and hangers, 40; counters, 40; other members in trusses and main girders when loaded length is 20 ft or less, 25; when loaded length is 200 ft or more, 10.

Allowable Stresses in lb per sq in.

TENSION. Axial, on net section, 16 000, K, O, M; floor beam hangers, 8 000; sway bracing, lateral forces, 18 000; sway bracing live load, 15 000; solid rolled beams, 13 000; bottom flanges, plate girders, chords, webs of trusses, 12 500 live, 25 000 dead, verticals carrying floor beams, 10 000 live, 20 000 dead, C.

COMPRESSION, axial gross section, $S = 16\ 000 - 70\ L/r$, O, K. S = allowable unit stress; L = unsupported length, inches; r = least radius of gyration, inches

$$S = \frac{12\ 000}{1 + \frac{1}{20\ 000}\frac{L^2}{r^2}}\ \text{M.}$$

Chord segments, $S = 12\ 000 - 55\ L/r$; posts of thru bridges, $S = 10\ 000 - 45\ L/r$; posts of deck bridges, $S = 11\ 000 - 40\ L/r$. For dead load, use twice these values. Lateral struts and rigid bracing, $S = 13\ 000 - 60\ L/r$, C.

Bending extreme fibers rolled shapes and built sections 16 000, K, O; extreme fibers, pins, 24 000 K, O, M; pins 20 000, C.

Shearing, plate girder webs, gross section 10 000, K, O; pins and shop rivets 12 000, K, O; 10 000 except 8 000 for floor system and 15 000 for laterals, C; 11 000, M; field rivets, allowable stress reduced 33.3%, C; 10 000, K; when power driven 11 000, hand driven 9000, O; when power driven reduce allowable stresses 10%, hand driven 25%, M.

Bearing, pins 15 000 live, 30 000 dead, C; 22 000, M; 24 000, K, O. Shop rivets 18 000 except 14 400 for floor beams and 27 000 for lateral, C; when area is enclosed between other pieces 20 000, not enclosed 18 000, M. 24 000, K, O. Field rivets reduce allowable stress 33.3%, C; 20 000, K; hand driven 18 000, power driven 22 000, O; reduce allowable stress hand driven 25%, power driven 10%, M.

Bed Plates and Rollers, bearing on masonry 250 lb per sq in, C; 400, M; 400 to 600, K, O. Bearing on expansion rollers in lb per lin in 300 *d*, C; 600 *d*, M, O, K; *d* = diameter of roller in inches.

Details of Design and Construction.

Proportion of Parts. Alternate Stresses: Members subject to alternate stresses shall be proportioned to resist each; increase both stresses by 30% of least of two stresses; rivets and bearing areas on pins increased 50% over usual, C; proportioned to resist maximum of each kind, but unit stress is less than stress of one kind, as follows; if the two maximum stresses are same, unit stresses are ½ above tension and compression for live; if smaller is ½ larger, unit stresses are ¾ of above tension and compression for live and proportionally for other ratios, M; proportioned for stresses giving largest section. If stresses occur in succession, increase each by 50% of smaller: connections proportioned for sum of stress, K. Members subject to reversal of stresses shall be proportioned for equivalent stress equal to that stress which, when added to 50% of the other, will give the greater section, both impacts added, O.

Counters: Area found by taking difference areas due to live and dead stresses separately, C, so that future increase in live load of 25% will not increase stress more than 25%, C, K.

Combined Stresses: Members subjected to both axial and bending stresses shall be designed so greatest fiber stress shall not exceed allowable unit stress, K, C; if fiber stress due to dead weight of member exceeds 10% of its allowable unit stress, such excess must be considered, C, K; stresses from assumed wind loads not considered unless unit stress is greater than 30% of live and dead unit stresses (in which case section increased until unit stress does not exceed by more than 30% of the maximum fixed for live and dead) or unless wind and temperature stresses reverse stress, C; 25%, K; members receiving stress from vertical loads and from lateral or longitudinal forces, unit stress shall not exceed allowable by more than 25%, M. When combining stresses due to vertical forces with those due to lateral forces, including direct and indirect wind and bending due to wind, unit stresses may be increased 25% if this gives a greater area, O. When both direct and flexural stresses due to wind are considered, 50% may be added to allowable stresses for dead and live provided the area is not less than required for dead and live alone, or for dead, live, and direct wind, K.

Riveted Tension Members: Net section thru pin hole 33.3% net section of member and back of pin hole at least 60% of net section thru pin hole, C; same except 25% and 75%, M, K; same as M except minimum section back of pin hole equals that thru body of member, O.

Plate Girder Flanges: Flanges carry all moment, web, all shear, C; ⅛ gross section web used as flange section if properly spliced, K, M, O; gross area tension and compression flanges equal, C, M, K, O; compression flange braced at distance equal to 16 times width, C; 12 times, O; 12 ft, K; if not braced at distance 20 times width allowable stress reduced, M; 40% flange area in angles, O; 50%, C; flange plates to extend beyond their theoretic length 2 rows of rivets at each end, C, M; 12 in O; flange plates not to extend more than 5 in or more than 8 times thickness of thinnest plate beyond outer line of rivets, C, M.

Plate Girder Webs: Net section carry total shear, M; gross section carry total shear, O; minimum thickness 5/16 in, K, C, M; not less than 1/160 unsupported distance between flange angles, O, K.

STIFFENERS: Webs to be stiffened at bearings and concentrated loads and at intervals not to exceed depth girder or 5 ft; whenever shearing stress in web exceeds 12 500 − 90 h/t, where h = depth and t = thickness web, inches, C, K; wherever shearing stress exceeds 12 000 ÷ [1 + (d^2 = 3000 t^2)] where t = thickness web, inches, and d = clear distance, inches, between flange angles, M; allowable stress in stiffeners 16 000 − 70 L/r, K, O; 12 000 − 55 L/r C;

MINIMUM THICKNESS OF METAL: 5/16 in main members, 1/4 in laterals, C; 5/16 in classes A, B and C, 1/4 in classes D, and D., K; 5/16 in, 1/4 in for channel webs, O, M; over steam railroad 3/8 in below floor, M.

COMPRESSION MEMBERS: L/r not more than 100 except laterals 120, M, C; same except 125 and 150 for classes D_1 and D_2, K; 120 and 140, O; abutting joints when faced for bearing, shall be spliced four sides to keep members in place, all other joints in riveted work to be fully spliced, C, K, O; all joints in riveted work fully spliced, M; unsupported width (between rivets) of cover plates not to exceed 30 times their thickness except cover plates, top chords and end posts which are limited to 40, C, K; 48, O; pitch of rivets not to exceed 4 diameters of rivet for length equal to twice width of member, C, M, O; and for length equal 1 1/2 times width, K; when necessary pin holes shall be reinforced by plates, K, O, M, C.

BATTEN PLATES: Placed near ends of compression members, length not less than greatest width member or 1 1/2 times its least width, C, K; length not less than greatest width and thickness not less than 1/50 distance between connecting rivets, M; not less than width of member, minimum 10 in, O.

LATTICING: Thickness not less 1/40, for single bars and 1/60 for double bars riveted at intersection, of distance between rivets connecting them to member, M, K, O, C; minimum of 5/16 in, M; width not less, for 15 in channels or built sections with angles over 3 in, than 2 1/2 in, M, O; for 12, 10, 9, 8, and 7 in channels, 2 1/4 in, M; 12, 10, and 9 in, 2 1/4 in, 8 and 7 in, 2 in, 6 in or less, 1 3/4 in, O; 18 in and over, 2 1/2 in, 15 in, 2 1/4 in, K; 2 1/2 in, C; 12 in, 2 in, K; 2 1/4 in, C; 9 in 1 3/4 in, K; 2 in, C; 6 in, 1 1/2 in, K; 1 3/4 in, C; single latticing inclined not less than 60° to axis member, double latticing, 45°, C, O, M, K.

RIVETS: Minimum pitch 3 diameters of rivet, maximum 6 in or 16 times thinnest outside plate connected, C, O, M, K; distance from edge never less than 1 1/2 or 2 diameters of rivet, C, M; for 7/8 in rivets, 1 1/2 in; 3/4 in rivets, 1 1/4 in; 5/8 in rivets, 1 1/8 in; from sheared edge and from rolled edge 1 1/4 in, 1 1/8 in and 1 in respectively, O, K; not more than 8 times thickness plate, M, O.

ROLLERS AND BOLSTERS: Spans 80 ft and over, resting on masonry, to have turned rollers or rockers at one end, less spans to have one end sliding, K, O, M; 100 ft and over, C; rollers 3 5/8 in diameter for spans 100 ft or less; increase 1 in for each 100 ft additional, C; same save for 100 ft or less diameter 3 in, K; in any case not less than 3 in; not less than 4 in, O; spans 80 ft or over have hinged bolsters at each end, O, M; 100 ft or over, C.

CAMBER: All bridges to be cambered by giving panels of top chord an excess length of 3/16 in in 10 ft, C, K; 1/8 in in 10 ft, M, O.

FLOORS. Floor beams shall be rolled or riveted steel girders, rigidly connected to the trusses at the panel points, C, K; may be placed on top deck bridges at panel points, K; all longitudinal girders of bridges classes A_1 and A_2, all track stringers classes B and C will be steel; unless otherwise specified, all other longitudinal girders classes B and C will be of steel; all longitudinal girders class D shall be either steel or wood, C; all joists and stringers classes A and B shall be of steel, joists for classes C, D_1 and D_2 either wood or steel, K; steel stringers shall be securely fastened to cross floor beams, C, K; width of wooden joists not less than 1/4 depth or 3 in, C, K; wooden joists not spaced over 2 ft centers and will lap by each other so as to have a full bearing on the floor beams, will be separated 1/2 in for free circulation of air, C; same except 2 1/2 ft centers, K; when spaced 2 ft centers, one joist to be considered carrying only 3/8 concentrated live load, C; same except 1/2, K. For single thickness, floor plank shall not be less than 2 1/2 in thick for oak or 3 in for pine, nor less than 1/12 the distance between centers of joists, laid transversely with 1/4-in openings; for additional wearing surface use a thickness of 1 1/2 in in which case lower plank 2 1/2 in thick shall be laid diagonally, K. Floor plank to have thickness in inches at least equal to distance apart of beams in feet or a minimum of 2 1/2 in, C. Footwalk plank 2 in thick and not more than 6 in wide with 1/2 in openings, C, K; in city bridges with buckle plate

floors, buckle plates not less than 5/16 in thick and crown not less than 2 in, C, K; bridges with buckle plate floors shall have suitable metal curb on each side of roadway to hold paving and act as wheel guard; wheel guard so arranged that it may be removed and replaced when worn or injured; there will also be a metal edging strip on each side of footway to hold paving in place, C; same except curb may be stone or steel, K; concrete over buckle plates at least 3 in thick on roadway and 2 in on sidewalks, C, K.

5. Shears and Bending Moments in Beams and Trusses

Altho this subject belongs in the part of Sect. 2 dealing with MECHANICS, and is there explained in principle, it appears necessary to show its application to beams and trusses. Notation: w = uniform load per foot, L = length of span; x = distance from left reaction to section considered; R_1 = left reaction; R_2 = right reaction.

Vertical Shear is the algebraic sum of the vertical forces on either side of a section. If upward forces are called plus and downward forces minus, the algebraic sum on one side of a section in a structure in equilibrium must be equal to and of opposite sign from that on the other side, since $\Sigma V = O$. The sign of the shear is arbitrarily fixed as positive when upward on the left and downward on the right of a section. In order to find the shear, it is therefore necessary to find all of the vertical forces on one side of the assumed section. In general, choose the side which requires the lesser work. In beams which are free at one end, work from the free end.

Bending Moment at a section is equal to the algebraic sum of the moments of the forces on either side of the section about an axis in the section. The sign of the bending moment is usually called positive when the algebraic sum of the moments on the left of the section is clockwise. In a beam on two points of support, a positive moment causes compression in the top fibers and tension in the bottom fibers. The sum of the moments of the forces on one side of a section will have the same numerical value, but the opposite direction, as the sum of the moments of the forces on the opposite side.

Curves of Shear and Moment. If the value of the shear, or moment, is found for different points thruout the length of the beam for some fixed loading and these values are plotted and connected by lines, the resulting curve is called the CURVE OF SHEARS, or the CURVE OF MOMENTS. Such a curve is of assistance in showing graphically where the maximum and minimum values of these functions occur. It will be noticed that at the point where the shear passes thru zero, the moment will be a maximum.

Influence Lines. An influence line shows the effect of a load of unity passing over the structure, at some particular section, on some particular function such as shear, moment, or stress. It is constructed for a load of unity, and for a particular section. As the load of unity passes over the structure, the value of the function under consideration is plotted below the load, thus forming a curve, the ordinate to which at any point is the value of this function, at the section assumed, due to the load of unity over the ordinate. It is oftentimes used to study the position of the loading which will give a maximum or minimum of the function under consideration.

Two General Cases must be considered for both shear and bending moment. Case 1. BEAMS WITHOUT FLOOR BEAMS. Case 2. BEAMS WITH FLOOR BEAMS. Each of these cases must be considered for both DEAD LOAD and LIVE LOAD. Case 1 includes the conditions of loading usually applied to the stringers of any bridge, while case 2 includes the condi-

tions usually applied to the girders or trusses when floor beams are used. Altho case 2 is made to include concentrated or wheel loads, it should be noted that the stresses in the trusses or girders of highway bridges are usually found by considering a uniform live load which may be reduced to concentrated panel loads, and applied at the panel points. When such loadings are used, the rules for finding the position of the loads to give a maximum moment or shear are simplified as indicated.

Case 1. Shear with Dead Loads. In a beam on two points of support fully loaded with a uniform load, R_1 is $\frac{1}{2}\, w\, L$ and the shear at any section will be $\frac{1}{2}\, w\, L - w\, x$. At the center of the beam this becomes zero. To the right of the center it is negative. At an infinitely small distance to the right of R_1 the shear will be a maximum with a positive sign and will equal R_1. In case the uniform load does not cover the entire space, and only extends a distance b from the left end, R_1 will equal the value given by the formula for R_1, and the shear at any section will equal R_1 minus the load from R_1 to the section in the same manner as before. At an infinitely small distance from R_2 the shear will be a maximum with a negative sign and will equal R_2. In case concentrated loads are upon the span, R_1 is found due to these loads and the shear at any section is equal to R_1 minus the loads between R_1 and the section. The total shear for both uniform and concentrated loads is the sum of each shear found as indicated above.

$$R_1 = \frac{w b\left(\frac{b}{2} + L - b\right)}{L},$$

Case 1. Bending Moment with Dead Loads. In a beam on two points of support fully loaded with a uniform load, R_1 is $\frac{1}{2}\, w\, L$ and the moment at any section is $\frac{1}{2}\, w\, L\, x - w\, x^2/2$. At the center of the beam, the moment is $\frac{1}{4}\, w\, L^2 - w\, L^2/8 = w\, L^2/8$. The moment at each end of the beam is zero. The maximum moment comes at the center and the curve of moments is a parabola, with its origin at the highest point and axis vertical. The sign of the moment is positive thruout the span. In case the uniform load does not cover the entire span find R_1, as in the case explained for shear, the moment will equal $R_1 x$ minus the moment of the uniform load, between R_1 and the section, about the section. In case concentrated loads are upon the spans, R_1 is found due to these loads and multiplied by the distance to the section, and the moments of any loads coming between R_1 and the section subtracted therefrom. The total moment for both uniform and concentrated loads is the sum of each moment as indicated above.

Case 1. Shear with Live Loads. A live load may be either uniform or concentrated. To find the maximum positive shear at a section X, the load is moved on the structure from the right up to the section. The shear will equal R_1. To find the maximum negative shear move the load on from the left up to the section and the shear will equal R_1 − load, or R_2. In order to find the maximum positive shear due to concentrated loads, the position of the loads causing a maximum must first be found. In Fig. 8, let $P_1 + P_2 + P_3 + P_4 = P$. Move up the system until P_1 is at the section. The shear is now equal to R_1. Now move the system until P_2 is at the section. The shear will be increased provided the increase in R_1 is greater than P_1, which must now be subtracted from R_1 to obtain the shear under this last loading. In general, move up the loads until a position is found where the increase in R_1 becomes

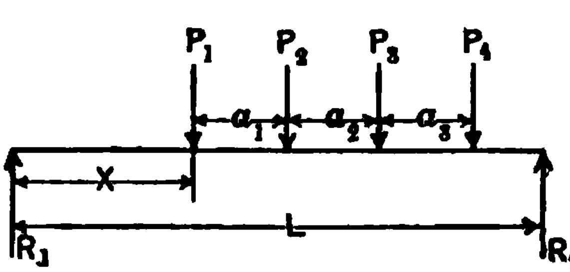


Fig. 8

less than the sum of loads to the left of section, and then move the system back to the right until the next load to the left is at the section. It may become necessary to consider the effect of a new load which may come on the span from the right, or a load which may leave the span on the left, provided such a condition occurs during the operation of moving from the load at the section to the next one. The maximum end shear will be equal to the maximum R_1 which can be obtained. It will usually occur when a heavy load is over R_1 and the other loads as near as possible. In general, begin by placing a heavy load at R_1 and move up the system so that the next load will come at this point. The end shear will be increased by so doing, provided that the increase in R_1 due to moving up the entire system is greater than the load first placed at R_1, which is now moved off. Proceed until the opposite condition is found and then move back to the right until the next load to the left is over R_1.

Case 1. Moment with Live Loads. The position of the loads for a maximum must first be determined. In general, the average load on the right of the section must be equal to or greater than the average load on the left. With a uniform load it can be placed so that $w/(L - x) = w/x$. In the case of one concentrated load, it should be placed at the section. In the case of several concentrated loads, the method of moving up the loads is to be used, first placing some heavy load at this section. In applying the above rule, always consider the load at the section as being in the sum on the right. Move up the loads until a load is found which, when considered in this sum, gives the average on the left greater than the average on the right, and then move the system back one load toward the right. Find the moment under this load. In a long series of concentrated loads, several positions may be found which will satisfy the rule. In general, the moment must be calculated for each and the largest result taken.

Absolute Maximum Moment. This applies to beams without floor beams only. The section where the largest moment due to concentrated loads occurs is not known. From mechanics it is shown that the bending moment is a maximum when the shear passes thru zero, but this point changes position with the moving loads. In general, this section will be as far from one end of the beam as the resultant of all the forces is from the other. In applying this rule, find, by the rule in the previous paragraph, the load which gives a maximum moment at the center of the beam. Find the position of the resultant of all the loads on the structure and move the loads so that the load which gave a maximum at the center is as far from the center on one side as the resultant is on the other. See if shear passes thru zero at this load and if so, find the moment under it. Due consideration must be given to any loads which pass on or off the beam in the process of placing the resultant on one side or the other of the center of the beam.

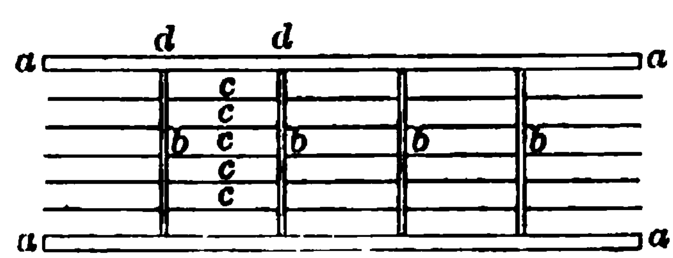


Fig. 9

Case 2. Shear with Dead Loads. In order to understand the action of floor beams upon shear and moment, the path by which the loads are conducted to the reactions must be fully comprehended. Fig. 9 shows the arrangement of the floor of a highway bridge: *aa* represents the girders or trusses; *bb*, the floor beams; *cc*, the lines of stringers, and *dd*, the

panel points. The load is first taken from the plank floor of the bridge to the stringers and then by the floor beams to the girders and by them is transmitted to the reactions. It may thus be seen that no load can be applied directly to the girders between floor beams except its own weight, as any load coming on the floor between must be distributed by the stringers to adjacent floor beams. The shear will then be constant between panel points for any particular loading. The shear in a panel as ab, Fig. 10, due to a uniform dead load will be $R_1 - w\,a_1 - w\,p/2$. In other words, not only the load to the left of a must be subtracted from R_1 but also the panel reaction at a due to the load in the panel.

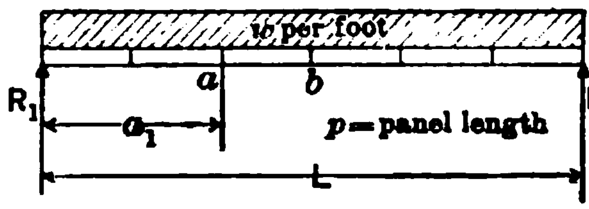


Fig. 10

CASE 2. MOMENT WITH DEAD LOADS. In Fig. 11, a, b, c shows the curve of moments for a beam without floor beams, while a', b', c' shows the curve for the same span introducing the floor beams. It may be seen that the moments for both curves are the same at the panel points and that between panel points the moments with floor beams are less. Find the moments at the panel points in the same manner as in CASE 1, UNIFORM LOAD.

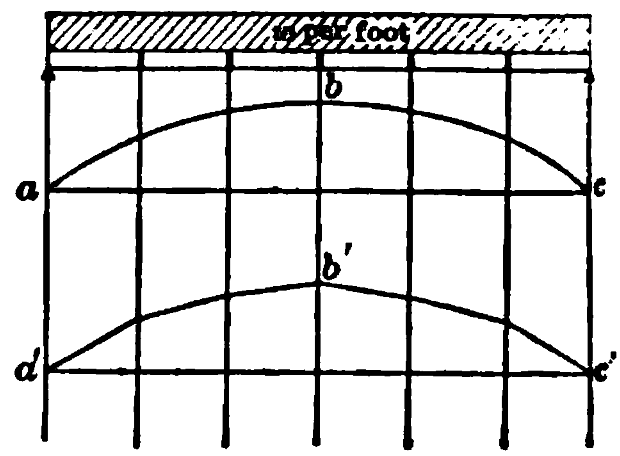


Fig. 11

CASE 2. SHEARS WITH LIVE LOADS. To find the maximum positive shear in any panel with a system of concentrated loads, the loads are moved on from the right up to the panel considered. In general, with the usual loads, no loads will pass beyond the panel. Move the loads up, always considering the load at the panel point to be included in the sum to the right, until a position is found where the average in the panel is greater than the average to the right and then move back to the previous position and calculate the shear in the panel. For highway bridges where panel concentrated loads are usually applied only at the panel point, this rule reduces to loading all panel points to the right of the panel considered.

CASE 2. MOMENTS WITH LIVE LOADS. This condition reduces to CASE 1 as the moments at the panel points are the same as if no panels existed. If, however, panel loads are used, load each panel point to obtain a maximum moment at any panel point.

The Maximum Floor Beam Reaction is the largest reaction which can be obtained in any floor beam and is found by loading the stringers on each side of a floor beam as heavily as possible. In the case of a uniform live load, the entire floor and sidewalk, if any, between two floor beams is loaded and the amount carried by each stringer to the floor beam is calculated. The reaction of the floor beam due to these loads is then found. The dead load of the floor covering and weight of stringers is also found and concentrated on the floor beams at the stringer connections from which, together with the weight of the floor beam itself, the dead reaction may be found. In case it is necessary to investigate also for concentrated loads (see Art. 4, LIVE LOAD), such as heavy teams, electric cars, road rollers, etc, the problem becomes more complicated. For this condition, place the concentrated loads so that one axle will be over

the floor beam and, taking into account the space occupied, load the remainder with uniform load. Then find the reaction of all stringers which support the load and this will give the amounts transmitted to the floor beam. Lastly, find the reaction of the floor beam due to these concentrations.

6. Steel Highway Bridges

Rolled Beams of steel are made in various shapes, the two most common being the I-beam and the channel. Properties of these shapes may be found in the various steel handbooks, see (6) and (7). Beams are designed by the formula $M = SI/c$ where M is the maximum moment in inch-pounds, S is the allowable unit value of the material, I is the moment of inertia of the section about its neutral axis, and c is the distance from the neutral axis to the extreme fiber. In this formula I/c is constant for any given beam and is tabulated as SECTION MODULUS.

EXAMPLE. **Design a steel I-beam 16 ft long to carry a load of 300 lb per ft which includes the weight of the beam. Allow a fiber stress of 10 000 lb per sq in.**

$M = \frac{1}{8} \times 300 \times 16 \times 16 \times 12 = 115\,200$ in lb.

$M/S = I/c = 11.5$. **From CARNEGIE we find a 7 in 17.5 lb I has a section modulus of 11.2, and an 8 in 17.5 lb I, a modulus of 14.6. Either of these would probably do, but the latter would give a greater strength for the same weight per ft.**

Beam Bridges are bridges made up of I-beams or channels, or both, with their ends resting on abutments (see Fig. 12). The number of beams necessary depends upon the loading and they are usually from 2 to 3 ft apart. Spiking pieces are bolted on the top of each beam to which the plank flooring is spiked. A spacing of 3 ft would call for a plank flooring of about 3 in in thickness. The maximum economical length of such bridges is from 25 to 30 ft. Wooden railings may be used, altho iron pipe is to be preferred. In designing such a bridge, after the span length is found, the loading which applies to the probable traffic is taken from the specifications and the maximum moments on the stringers computed by the methods explained in Art. 5. After finding the moment, the I-beam may be designed as in the preceding example. In general, the side stringers will not receive as much load as those between them and may be made of channel sections which are designed in the same manner as in the case of the I-beams. In loading for maximum live load shear and moment, it is allowable, when considering concentrated or wheel loads, to assume that each stringer takes only ⅜ of the load directly above it, provided the floor plank is continuous.

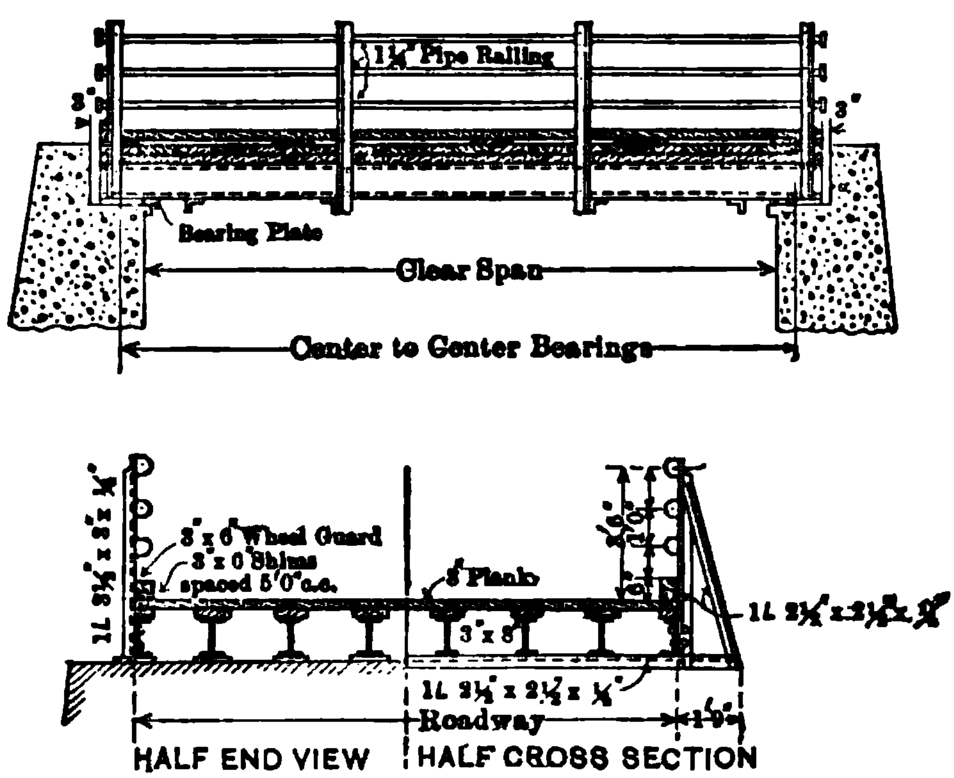


Fig. 12

Girder Bridges are usually of the plate girder type with the general arrangement as shown in Fig. 9. The stringers and floor beams are usually

made up of I-beams altho in some cases, it may be necessary to use built beams for the floor beams. The plate girder is a built beam and is made up of the WEB and FLANGES. The flanges are composed of angles, or angles and plates. A plate girder bridge may be either deck or thru. Unlike a railroad deck bridge, both kinds require stringers and floor beams, the principal difference being that in the deck highway bridge, the floor beams are placed with the tops higher than in the thru bridge. For ordinary traffic, two girders are required, while for heavy city traffic, including heavy electric cars, three or even four girders may be necessary, in which case a deck bridge should be used, if possible, in order to allow a clear roadway. The stringers of a plate girder bridge are designed in a manner similar to that explained for beam bridges. The floor beams, if made up of I-beams, may be selected in a manner similar to the stringers by finding the maximum moment, remembering that the live loads can only be applied at the stringer connection. If made up of built beams, the same general principles to be explained for the design of the girders, which are heavier built beams, will apply. Remember that the floor beam, unlike the girder, is a beam without panel points, and the rules for maximum shear and moment should be applied accordingly. In the design of the girders, the rules for moment and shear applied to CASE 2 apply. In designing a girder, the web is assumed to carry the shear and the flanges the moment. Hence, with the loading assumed, the maximum shear is obtained in each panel and the maximum moment at each panel point up to the center of the bridge.

Stiffeners. As the combined action of the horizontal and vertical shear tends to buckle the web, stiffeners are usually required to prevent this action. These are in the form of angles in pairs riveted vertically to each side of the web. It is the usual practice to provide two pairs of stiffeners at each end, the distance apart being a little less than the bearing plate directly under them. The distance apart of intermediate stiffeners differs slightly according to the various authorities. Cooper recommends that this distance shall not be greater than the depth of the girder with a maximum distance of 5 ft whenever the shearing stress per sq in exceeds the stress allowed by the formula, allowed shearing stress = 12 500 − 90H, where H = ratio of depth of web to its thickness. Cooper also recommends that all stiffeners, both end and intermediate, shall be capable of carrying the maximum vertical shear without exceeding the allowed unit stress as given by the formula, $S = 12\,000 - 55\,L/r$, where S = allowed unit stress; L = length of stiffener; r = radius of gyration of angles at right angles to the web, neglecting inclosed portion of fillers and web. Ketchum also gives the above formula for allowed shearing stress, but for the cross-section of the stiffener recommends the following: $S = 16\,000 - 70\,L/r$, where, in this case, L is one-half the depth of the girder. All stiffeners should connect to the webs by enough rivets to transfer the shear to or from the webs. End stiffeners and those under concentrated loads should be placed upon fillers and should have their ends fitted to the flange angles. Intermediate stiffeners may be placed upon fillers or crimped. In the latter case, this allows the stiffeners to rest directly against the web and at the flange angles it is bent or crimped to fit over these angles.

The Economic Depth of built beams used as girders is usually about from 1/8 to 1/10 of the span length. For short beams which carry the load directly, such as stringers when used with heavy loading, the depth

should be more, and for long girders it is usually taken from 1/10 to 1/12, with a maximum depth of about 10 ft on account of shipping.

The Design of the Web, having assumed the depth, consists of taking a plate of cross-section sufficient to withstand the vertical shear. If V = vertical shear, S_s = the allowable shearing value for web plates and A = the area required, then $A = V/S_s$. As there is usually a line of rivet holes near the section of maximum shear, the available net area will be approximately $\frac{3}{4}th$ where t is the thickness and h the height. Then $\frac{3}{4}th = V/S_s$. It is usual in girders designed under ordinary conditions to make the web of uniform cross-section thruout the span length. The minimum thickness of webs for highway bridges is 5/16 in. In many cases this requirement will call for webs which have an excess of metal.

Design of the Flanges. See Fig. 13. The flanges may be designed either by the moment of inertia of their net section or by assuming that the flange

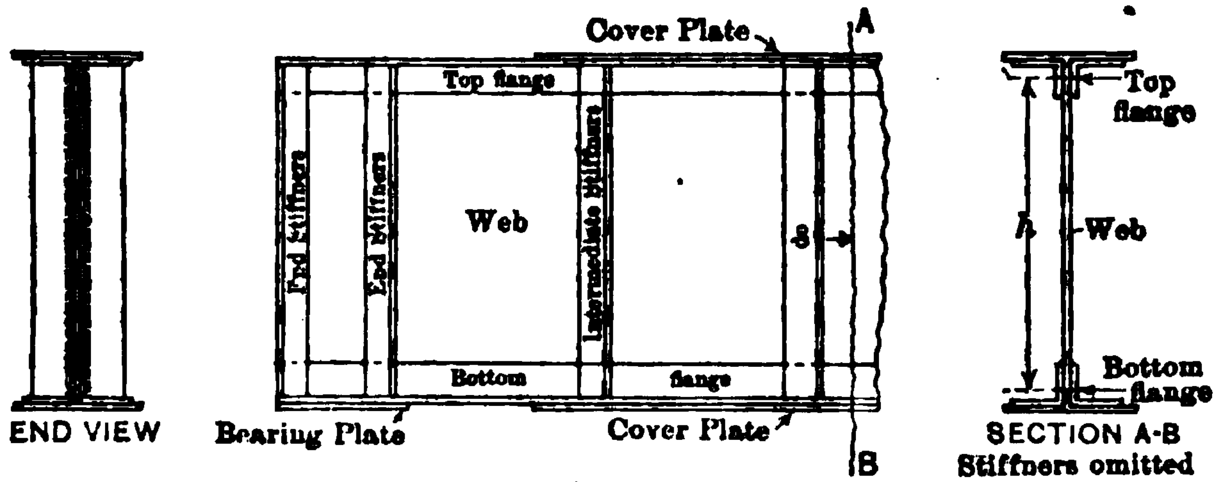


Fig. 13

areas are concentrated at their centers of gravity. The latter method is probably the more common. The flanges are assumed to carry the bending moment. This does not change the fact, however, that a portion of the moment must be borne by the web, and some specifications allow a reduction in required flange area due to this fact. If the latter method is used, it is common to allow ⅛ of the gross area of the web for flange section. If h is the distance between the centers of gravity of flanges, and M_r the resisting moment of the beam, P the total stress in each flange, then $M_r = P\,h$. As the resisting moment must equal the bending moment, $M = P\,h$ or $P = M/h$. Total area A required for one flange will equal P/S where S is the allowable unit stress. If the web is assumed to carry its share of the moment, ⅛ of its area is subtracted from the total area as determined above. The tension flange is usually designed first and the same section used for the compression flange, but the latter must be stayed against transverse crippling at a distance apart not to exceed from 12 to 14 times its width. In case this is not possible, it must be designed as a column by applying a column formula which will reduce the allowable unit stress depending upon the values of its length and radius of gyration, the latter taken about a vertical axis. In making up the section of a plate girder, it is a common requirement that at least ½ the area of the flange section shall be angles or else the largest size of angles shall be used. Other authorities require 40% to be in the angles. The remainder of the area, whichever method is used, is in cover plates. Also the width of the cover plates are limited so as not to extend beyond the outer line of rivets, which connect them to the angles, more than 5 in or more than eight times the thickness of the first plate. Where two or more plates are used as cover

plates, they shall be of the same thickness or else they shall decrease in thickness outward from the angles.

Rivet Spacing in Flanges. Let V_h = horizontal shear per lin in; V = total vertical shear at point considered; Q = statical moment about neutral axis of the portion outside of the section upon which the horizontal shear is to be obtained; I = moment of inertia of whole section of girder about neutral axis, and h = distance between centers of gravity of flanges. Then $V_h = VQ/I$. Various approximations are used for this exact expression, the most common of which is $V_h = V/h$. To obtain the rivet spacing in the vertical legs of the flanges, find the vertical shear at various points and from these find the horizontal shear as above, usually using the approximate formula. Divide the rivet value by the horizontal shear and make the spacing equal to or less than the quotient. This spacing is the distance between center of rivets measured horizontally. In built stringers, compute the horizontal shear at two or three points between end and center; in deck girders, every 2 to 6 ft. Vary the spacing to merge from one result into another. In thru girders, as the live vertical shear is constant between panel points, the maximum dead shear may be added and the spacing be made uniform in each panel. It is, however, a general rule that in no case shall the spacing of rivets be less than three diameters of the rivet or more than 6 in. In the case of beams used as stringers covering concentrated loads, the rivets carry a direct vertical shear in addition to the horizontal shear, and in such cases the resultant shear is the one to be used with the rivet value to find the rivet spacing. To obtain this resultant shear, assume that the concentrated load, coming over the point under consideration, is being transmitted thru the flooring and into the beam and extends over a distance of 3 ft. Then the square root of the sum of the squares of 1/36 of concentrated load and the horizontal shear per linear inch will give the resultant shear per unit. The rivet spacing in cover plates is usually made the same as that figured for the vertical leg, altho, if thought necessary, it may be obtained in a similar manner to that already explained.

Cutting off Flange Plates. Two methods may be used, the analytical and the graphical. In the first, since A, the area required = M/Sh, an expression may be written for M at any point in terms of X, the distance from left support, and this put equal to $A_1 hS$ in which A_1 is the flange area minus the top plate. Solving for X, the distance from the end reaction to a point where the top plate is not required is obtained. Apply the method as many times as there are plates, A_2 being the flange area minus two plates, etc. This method can only be used where an expression for M may be easily written.

In the graphical method, lay off to some convenient scale at the proper points on a straight line perpendiculars which represent the flange area required at each point (see Fig. 14). In the case of a thru girder, these points will be the panel points and the diagram will be drawn for the net area required in the bottom flange at these points. The area will be determined by $A = M/Sh$ where M is the moment at the particular panel point.

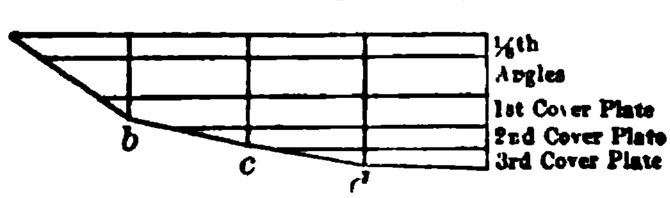


Fig. 14

Connect the ends of these perpendiculars by a curve or a broken line, remembering that the moment varies uniformly between panel points for all except the dead weight of the girder. Measure off on a perpendicular

at the center to the same scale as before, (1) ⅛ area of web, if used, (2) net area of flange angles, (3) net area of the several plates. Draw thru these points horizontal lines and the intersection of these with the broken or curved line will show the points where the several plates may be cut off. Each plate should, however, be extended about 1 ft beyond the point, and it is usual to run the bottom plate of the top flange to the ends of the girder.

Flange Splicing. When the length of the girder exceeds about 60 ft, the flange angle and plates should be spliced. The splice angle or splice plate should contain the same net area as the angle or plate to be spliced, and should have rivets enough to develop the section spliced, that is, to carry the stress value out of the cut member into the splice piece and back into itself again. Where there are several plates in a flange, cut off according to the method as explained, splices for the longer plates are frequently made by increasing the length of the plate on top of it a sufficient distance for a splice plate and cutting the plate to be spliced underneath. As a splice is considered to be a point of weakness, they should be distributed, that is, flange angles should not be spliced at the same section. It is customary to splice them on opposite sides of the center.

Web Splicing. When a web plate can not be obtained of a length equal to the span of the girder, it must be spliced. For lengths of plates, see the various steel handbooks. The splice is made by two plates, one on each side of the web. If the web is assumed to take a part of the moment, it must be spliced for both shear and moment. If all the moment was assumed by the design to be taken by the flanges, then the splice need be made for shear alone, altho some authorities claim that the web should always be spliced for moment and that in many cases under this condition shear may be neglected. In either case, it is first necessary to assume a splice with say two rows of rivets spaced from 3 to 4 in apart on each side of the cut web, and test it for the given conditions. In the case for shear alone, assuming two rows of rivets, divide the maximum shear at the splice by the number of rivets to find the stress r_s per rivet due to shear. In case the bending moment is considered r_1, the value left for bending is $\sqrt{r^2 - r_s^2}$, where r is the value of one rivet, in this case probably in bearing on the web. Suppose in Fig. 15*a*, the outside rivet at distance y_1 from the neutral axis to be stressed to this moment, then the load on any rivet at distance of y from the neutral axis will be $y\ r_1/y_1$ and the moment of this about the neutral axis will be $y^2\ r_1/y_1$ and the moment of a row of these will be

$$2 \sum_0^{y_1} y^2 \frac{r_1}{y_1} = 2 \frac{r_1}{y_1} \sum_0^{y_1} y^2 \quad (a)$$

The bending moment which the web can bear as a beam is SI/c which, for rectangular shapes, reduces to $1/6\ Sth^2$ (*b*). Then the required number of rows will equal (*b*) divided by (*a*). If the result is say 2½ rows, respace the rivets and try again. Fig. 15*b* shows a second type of splice which is used. The top and bottom splice plates are figured with their rivets to carry the moment and the vertical plate in the center to carry the shear.

(*b*) (*a*)

Fig. 15

Rivet Values. In considering the conditions to which rivets are usually subjected in bridge work, they may be reduced to those of (1) single shear and (2) double shear or bearing. In the first case, the rivets are assumed to fail by shearing off on the one area between the two plates. In the second case, shear will occur on two areas and the rivet is twice as strong provided the plate does not crush. The value of the rivet in single shear is the area of the rivet multiplied by its shearing value per unit area as determined by the specifications. The bearing value of the rivet is the diameter of the rivet multiplied by the thickness of the plate multiplied by the bearing value per unit area. In any case, determine the action to which the rivet is subjected and take the lesser value. Tables giving these values for different size of rivets may be found in the steel handbooks, see (6) and (7).

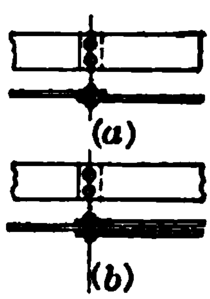


Fig. 16

Trusses are framed structures so proportioned and connected that they act together and carry the known loads to which they are subjected. In shape, a truss is usually made up of a combination of triangles. The different members are usually subjected to either tension or compression, and are connected together by either pins or rivets. A few members are designed to withstand both tension and compression, and occasionally a member is subjected to a live cross loading. The solving of a truss to find the stresses in the members is a problem, or a succession of problems in mechanics which generally depends upon the fundamental conditions for equilibrium for concurrent and non-concurrent forces. A truss is said to be STATICALLY DETERMINED with regard to the inner forces when it is possible, by the principle of statics, to obtain the stresses in all of its members. If n is the number of joints in a truss and m the number of bars, the condition that the structure shall be statically determined with regard to the inner forces is that $m = 2n - 3$. In determining the stresses, it is assumed that the parts are hinged together so that there is perfect freedom of motion without friction. This assumption is, however, never fulfilled and the rigidity of the joints causes a tendency for bending of the parts, and thus other forces, called secondary stresses, are brought into action. These latter forces are generally omitted from consideration even tho they may be of considerable magnitude. Two trusses connected together by means of the floor and lateral bracing form a bridge which may be either deck or thru. Fig. 17 shows a diagram of the different members. Sometimes trusses are used in which the top lateral bracing must necessarily be omitted on account of low head room. Figs. 18 and 19 show two such trusses in which will be noticed the method of side bracing which takes the place of the top lateral system. This type of bridge is apt to lack in lateral stiffness and should be used with care.

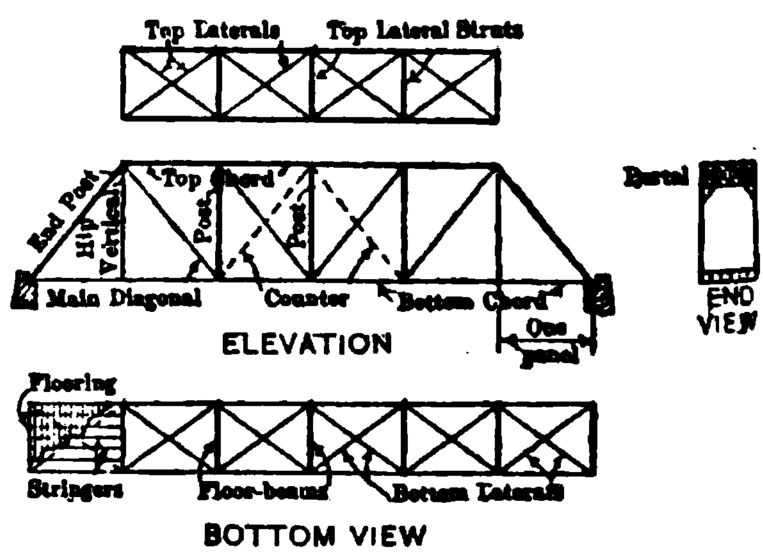


Fig. 17

PIN-CONNECTED trusses are used for highway bridges of about from 120 to 150 ft and over. RIVETED CONNECTIONS are used for spans of the shorter

lengths. In the pin-connected trusses, the tension members are usually eye-bars and all main connections of truss members are made by pins. If pins are not used, these connections are made by means of plates and rivets and the members are built sections, no eye-bars being used.

Types of Trusses. The most common types in use for steel highway bridges are the Pratt, Warren, Camel-Back, Baltimore, and Petit. Most of these are capable of modification. Fig. 20 illustrates the different types.

The Method of Computing Stresses is based upon the application of the three equations of equilibrium $\Sigma V = 0$, $\Sigma H = 0$, and $\Sigma M = 0$ upon

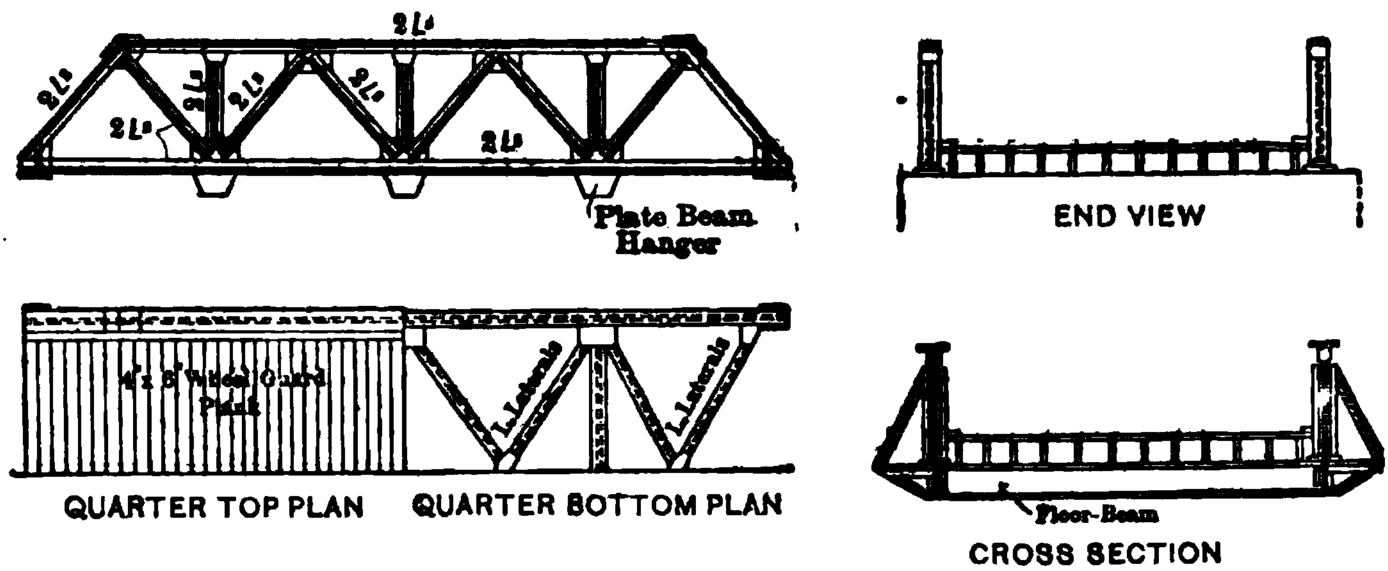


Fig. 18

a section of the truss. When the section is taken about a joint where all the members intersect, the last equation is eliminated. When the section is taken vertically or diagonally thru the truss, all three apply. In general, this application may be reduced to three methods: (1) METHOD OF SHEARS; (2) METHOD OF JOINTS; and (3) METHOD OF MOMENTS. It is usually possible to select the section in such a way that only one method need be applied in order to determine the stress in any one bar. In general, the method of procedure is as follows: (1) Take a section cutting not more than three unknown members. Never take the section thru a joint. (2)

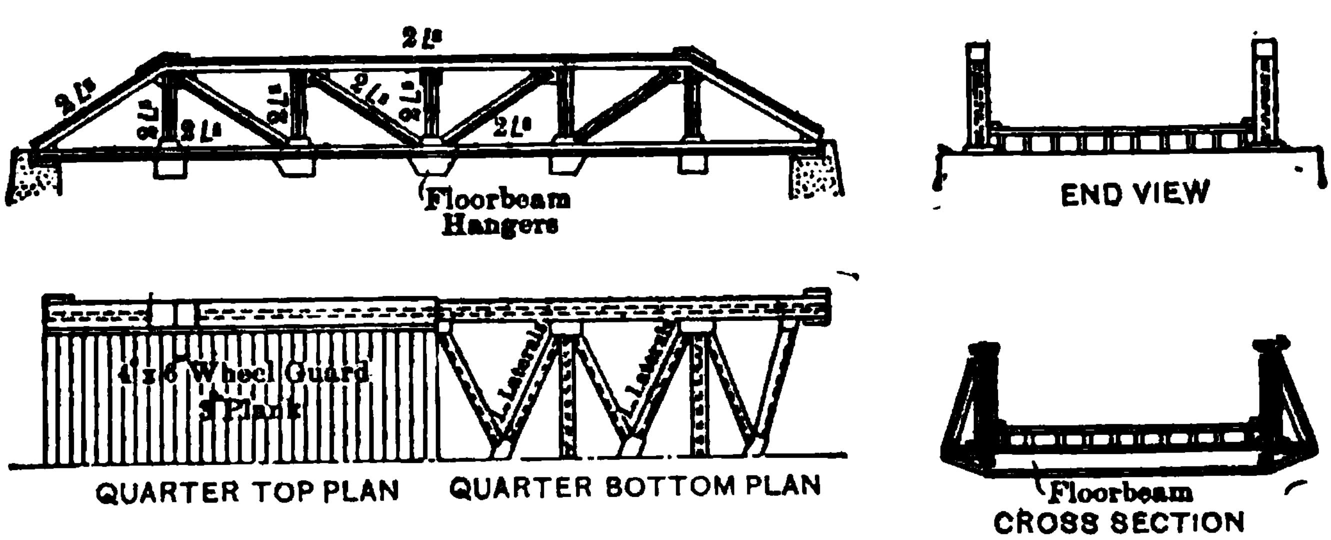


Fig. 19

Remove the truss on one side of the section. (3) Replace the cut members by forces. Place these forces outside of the section and assume compression to act toward the section and tension to act away from it. (4) Write

equations of equilibrium, and solve them for the unknown quantities. Usually the direction of the forces applied to the cut members will be known from the nature of the problem. If one direction is not known, it may

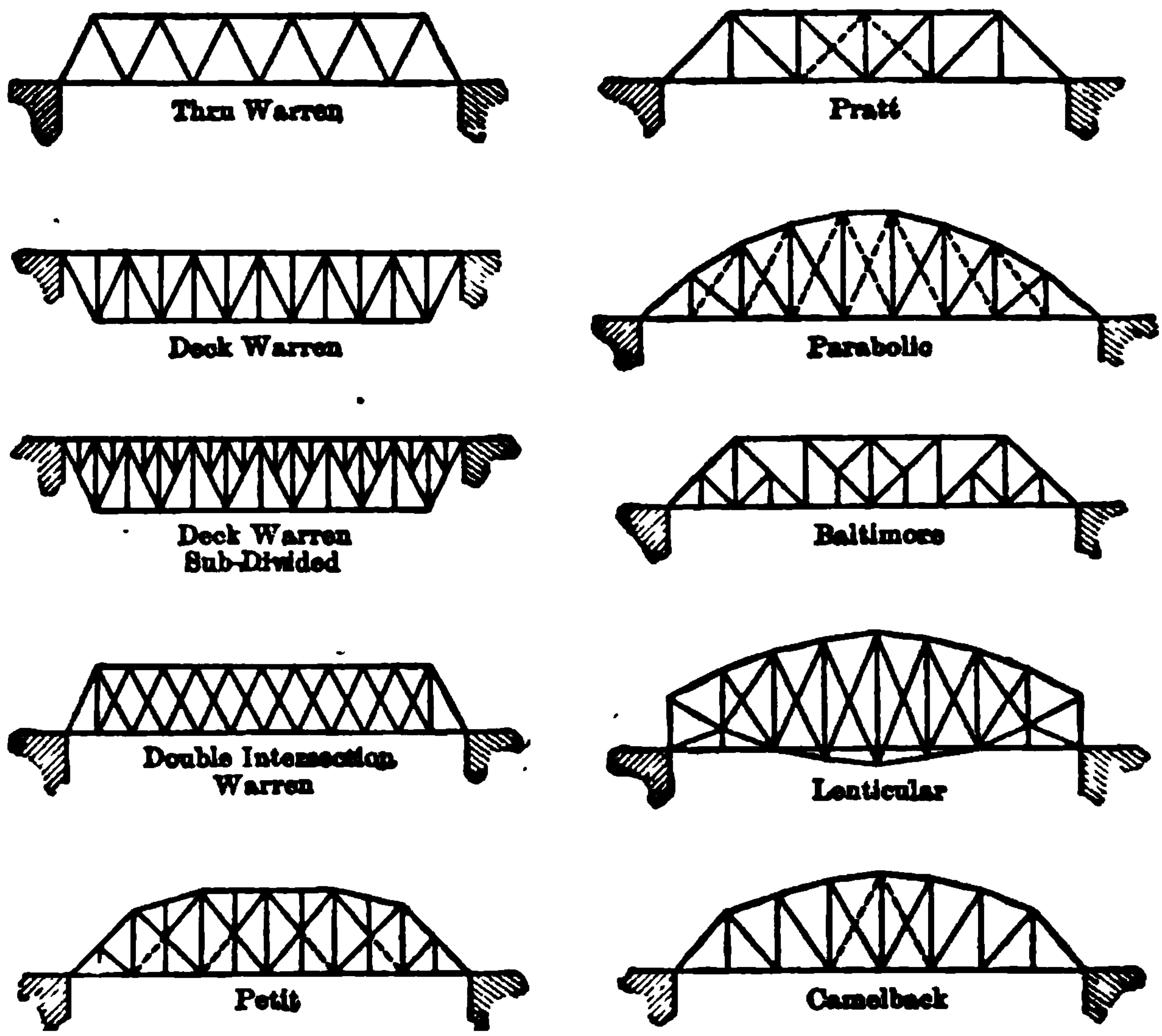


Fig. 20

be assumed, and if the resulting value as determined by solving the equation is negative, it should be reversed.

In Fig. 21*a*, suppose it is desired to obtain the stress in the diagonal member cut by section *m n*. Remove that part of the truss to the right of the section, and Fig. 21*b* results. It is known that under the loading the top chord is in compression and the bottom chord is in tension, hence place forces S_1 and S_2 as shown. Assume S to be in tension as shown. Writing $\Sigma V = 0$, $200 - 25 - 100 + S_{vc} = 0$, from which $S_{vc} = -75$, showing that S acts in the opposite direction or in compression. It should be noticed that instead of removing that portion of the truss to the right of the section, the left side could have been removed and the same result obtained.

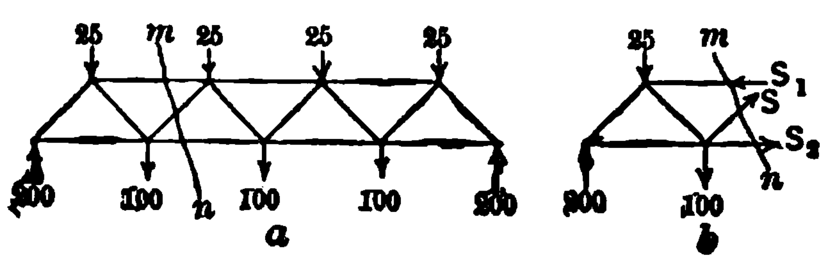


Fig. 21

Pratt Truss. As an example of the application of the foregoing principles, assume a truss as shown in Fig. 22. Width of roadway 17 ft, live load 1600 lb per ft of bridge, dead load 600 lb per ft. This will give panel loads of 16 000 and 6 000 lb for one truss. Assume ⅔ of the dead load applied to the bottom chord and ⅓ to the top chord.

Dead Load Stresses. Since the dead load is a fixed loading, the stresses caused by it may be conveniently found by a method of INDEX STRESSES, obtained by the METHOD OF JOINTS, as follows: Begin at joint U_2 and take a section around the joint as shown.

Remove the rest of the truss and place arrows on the forces cut, considering compression acting toward the joint (see Fig. 22*a*). Applying $\Sigma V = 0$, $-2 + s = 0$, or $S = 2$ in compression. Proceed to L_3, take section as before and apply $\Sigma V = 0$ (see *b*). $-2 - 4 + 2S = 0$. $S = 3$, in tension. Proceed to U_2 (see *c*). $-2 - 3 + S = 0$. $S = 5$, in compression. Proceed to L_2 (see *d*). $-5 - 4 + S = 0$. $S = 9$, in tension. Proceed to L_1 (see *e*). $-4 + S = 0$. $S = 4$, in tension. Proceed to U_1 (see *f*). $-2 - 9 - 4 + S = 0$. $S = 15$ in compression. Proceed to L_0 (see *g*). $R_L - 15 = 0$, $R = 15$. As $R_L = 2\frac{1}{2} \times 6 = 15$, these two results check. It should be noted that the values found are vertical components and, unless the member is vertical, these must be multiplied by L/h to obtain the

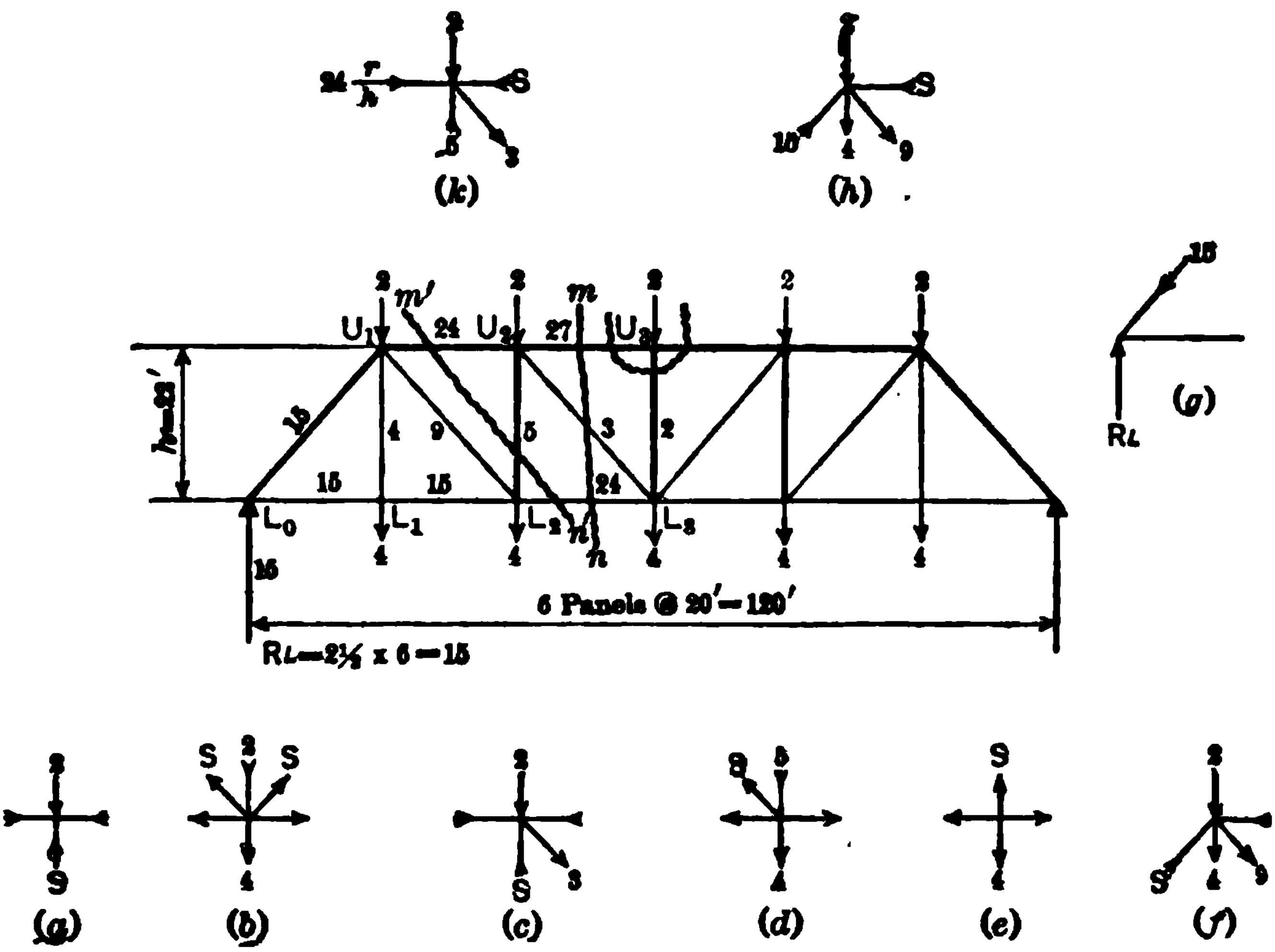


Fig. 22

stress, where L is the length of the member. Now, proceeding again to U_1, and taking a section around the joint, the forces are as in *h*. Apply $\Sigma H = 0$. $15\ p/h + 9\ p/h - S = 0$. $S = 24\ p/h$. Again, it must be remembered that both 15 and 9 are vertical components and to find the horizontal component of a force, having given its vertical component, multiply by the horizontal over the vertical in the triangle of forces, or if p is the panel length, multiply by p/h. Proceed to U_2 (see *k*). $24\ p/h + 3\ p/h - S = 0$. $S = 27\ p/h$. In this way, figures may be written on both top and bottom chords which, when multiplied by p/h, become the stresses in these chords. The top chord stress may also be obtained by the METHOD OF MOMENTS as follows: Take a vertical section such as *m n* cutting the top and bottom chords and the diagonal, and remove that part of the truss to the right, and apply $\Sigma M = 0$ at the intersection of the bottom chord and diagonal, the latter being also assumed as unknown. $15 \times 3p - 6 \times 2p - 6 \times p - Sh = 0$, from which $S = 27\ p/h$ as before. Any of the chords may be found in a similar manner. The diagonal stresses may also be obtained by the METHOD OF SHEARS as follows: Use the same section *m n* and remove that part of the truss to the right as before, apply $\Sigma V = 0$ to those forces on the left of the section. $15 - 2 \times 4 - 2 \times 2 - S = 0$, from which $S = 3$ as before. It will be noticed that the value of the shear on this section is 3, hence this method has been called the method of shears, and is applicable to any truss which has parallel chords.

Live Load Stresses. Usually take a section entirely thru the panel containing the member in question, and for chords load for maximum moment. For U_2U_3 take

section $m\ n$. Remove part of truss to right, and write moments of forces to left about L_3. The diagonal and bottom chord which are cut by this section, and are unknown, are eliminated because they pass thru L_3, the center of moments. As the chords may be considered to take the moment, a maximum moment is desired at L_3 which will occur with the entire bridge loaded. $R_L = 2\frac{1}{2} \times 16 = 40$. $40 \times 3p - 16 \times 2p - 16 \times p - Sh = 0$. $S = 65.5$. The maximum moment at the center is also $1/8 \times 16/20 \times \overline{120}^2 = 1440$. $1440/22 = 65.5$. As the web members take the shear, the live loading should be placed for a maximum shear on the section cutting the member considered. For U_2L_3 take section $m\ n$. Load from right to L_3. $R_L = (1 + 2 + 3)\ 16/6 = 16$. Apply $\Sigma V = 0$ using all forces to left of section, remembering that the top and bottom chord, altho cut, can not take a vertical component. $16 - S_{vc} = 0$ or $S = 16\ L/h$. For U_2L_2 take section $m'\ n'$, load for a maximum positive shear on this section, and the loading is the same as for U_2L_3. $R_L = 16$. $\Sigma V = 0$ gives $16 - S = 0$ or $S = 16$. U_1L_1 is a tension member and can only be stressed by a load on L_1. If the live floor beam reaction is larger than the panel load of 16, it should be taken in place of the latter for this member. To find whether a COUNTER, U_3L_2 is required, load for maximum negative shear on section $m\ n$. Place live load on L_1 and L_2. $R_L = (4 + 5)\ 16/6 = 24$. Shear $= 24 - 32 = -8$. This shows that for this loading U_2L_3 would be in compression, and as this compression is greater than the dead load tension, and as an eye-bar can take no compression, a member U_3L_2 is necessary. An investigation of the next panel to the left will show positive shear even when loaded for a negative, and no counter is needed.

Warren Truss. See Fig. 23. Assume a dead load of 700 lb per ft and a live load of 1600 lb per ft of bridge. This gives a live panel load of 16 000 lb for each truss. Assume the dead load to be distributed as shown.

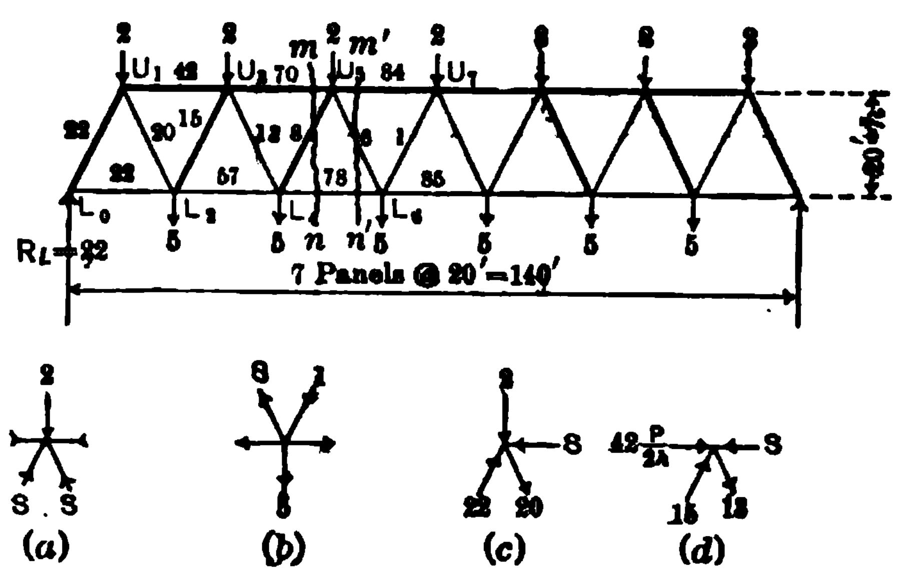


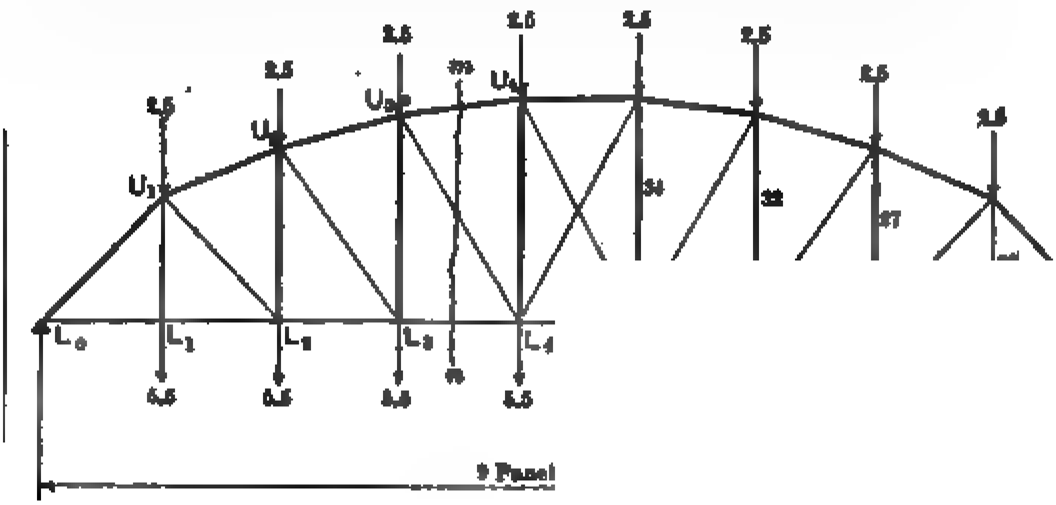
Fig. 23

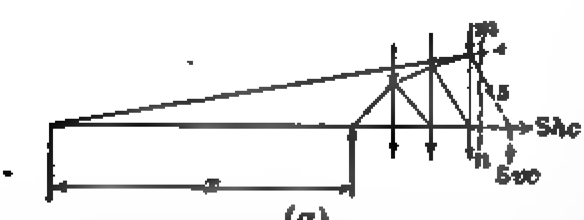
Dead Load Stresses may be found by writing index stresses. Take a section about U_7 (see a). Apply $\Sigma V = 0$. $-2 + 2S = 0$. $S = 1$. Proceed to L_6 (see b). $\Sigma V = 0$ gives $-1 - 5 - S = 0$. $S = 6$. Proceed in this way from joint to joint until R_L is reached. R_L also equals $3 \times 5 + 3\frac{1}{2} \times 2 = 22$, which checks the result already found. For the chords, take section at U_1 (see c). Apply $\Sigma H = 0$, remembering that the figures on the chords just found are vertical components. $22p/2h + 20p/2h - S = 0$. $S = 42\ p/2h$. Proceed to U_3 (see d). $42\ p/2h + 15\ p/2h + 13\ p/2h - S = 0$. $S = 70\ p/2h$. Note that the horizontal leg of triangle for reducing components is $p/2$. Check the last result by method of moments. Take section $m\ n$, and remove right part of truss. Take center of moments at L_4 and write moments of all forces to left of section. $22 \times 2p - 5 \times p - 2 \times 2p - Sh = 0$. $S = 35\ p/h = 70\ p/2h$. The bottom chords may be found in a similar manner, taking the center of moments above.

Live Load Stresses. As the loading for maximum moment at any section is a full one, the live load chord stresses may be determined in a manner similar to that explained for dead stresses. It should be noted that, if index stresses are written for live loading, the values written on the web members are of use only in determining the chord stresses, as web stresses have maximum values for partial loadings. To find the maximum stress in U_5L_6 take section $m'\ n'$ and load for a maximum positive shear on this section, or from the right up to L_6. $R_L = 10/7 \times 16 = 22.9$. Apply $\Sigma V = 0$ and the stress in member is $22.9\ L/h$ tension. The maximum stress in other web members may be found in a similar manner, always taking a section cutting the bar in question. Thus for U_5L_4 the section would be $m\ n$ and the loading the same as for U_5L_6, and the stress will be the same as before but will be compression. As no

counters are used in a truss of this kind, the web members must be investigated for a reversal of stress and if such is found they must be proportioned accordingly. Thus U_5L_4 is in tension under a full load or under positive shear. Load for negative shear on section $m\ n$. Load from left up to L_4. $R_L = (11/7)\ 16 = 25.1$. Shear on section is $25.1 - 32 = -6.9$. As the dead load tension is 6, this means that a reversal of 0.9 occurs. See Art. 4. The maximum negative live shear on $m'\ n'$ will also be 6.9 and, as the dead shear is 8 positive, no reversal can occur in this member or in any of the web members to the left. A reversal will occur in U_7L_4, and will be found by loading from the left up to L_4. Proceed as before.

Camel-Back Truss. See Fig. 24. This truss is also called the Parker Truss, and may be used for spans from about 175 ft to about 250 ft in length. The top chord approaches a parabola in form, the length of the hip vertical being made long enough to provide sufficient head room, and





(a)
Fig. 24

at the same time give a portal deep enough to provide sufficient stiffness. Assume a dead load of 800 lb per ft of truss and a live load of 1550 lb per ft of truss. This gives a live panel load of 15 500 lb per truss. Assume dead load distributed as shown.

Stresses. Altho the method of index stresses may be used for dead loads, it must be modified as the chords are not parallel. This method will be omitted here. The dead and live stresses may both be conveniently found by the method of moments. In general the chords will be a maximum for a full live loading and the web members will be a maximum for the live loading which gives a maximum shear on the section cutting the member. To find dead stress in $U_3\ U_4$, take section $m\ n$. Write moments about L_4. $R_L = 4 \times 8 = 32$ dead. $32 \times 4p - 8 \times 6p - S_{hc} \times 34 = 0$. S_{hc} = horizontal component $= 47.1\ S = 47.1\ L/p$ where L = length of member. The live stress may be determined by multiplying this value by the ratio of the live load to the dead load, or 15.5/8. The stress in this member could also be determined by taking the same section and applying $\Sigma V = 0$, after first finding the vertical component in $U_3\ L_4$ for this loading, which is not the loading for a maximum in this diagonal. This would obtain the vertical component of $U_3\ L_4$ instead of the horizontal. This result multiplied by $L/2$ should equal that found by the other method. To find the maximum stress in $U_3\ L_4$ take same section and load with live load up to L_4. $R_L = 32$ dead and 25.8 live. Find where $U_3\ U_4$ intersects the bottom chord and take this point as the center of moments, considering the diagonal $U_3\ L_4$ to be resolved into its horizontal and vertical components at L_4. Let X = distance from this intersection to L_0. $X +$

$4p : 84 :: X + 3p : 32$ from which $X = 13p$ (see *a*). Take moments about this point. $-32 \times 13p + 8\ (14p + 15p + 16p) + S_{vc} \times 17p = 0$ from which $S_{vc} = 3.3$ dead. $-25.8 \times 13p + S_{vc} \times 17p = 0$ from which $S_{vc} = 19.7$ live. To find the stress multiply these values by L/h. This must have counters in panels where, by loading for negative shear, the stresses in the main diagonals are reversed. The maximum stresses in diagonals, verticals, and counters may be found as explained for $U_3 L_4$, being careful to load correctly and use the proper center of moments. In the center panel, the chords are parallel, which simplifies the calculations for stresses in these members.

Baltimore Truss. See Fig. 25. This truss is of the Pratt type with a secondary system of webbing. This allows economy in the length of

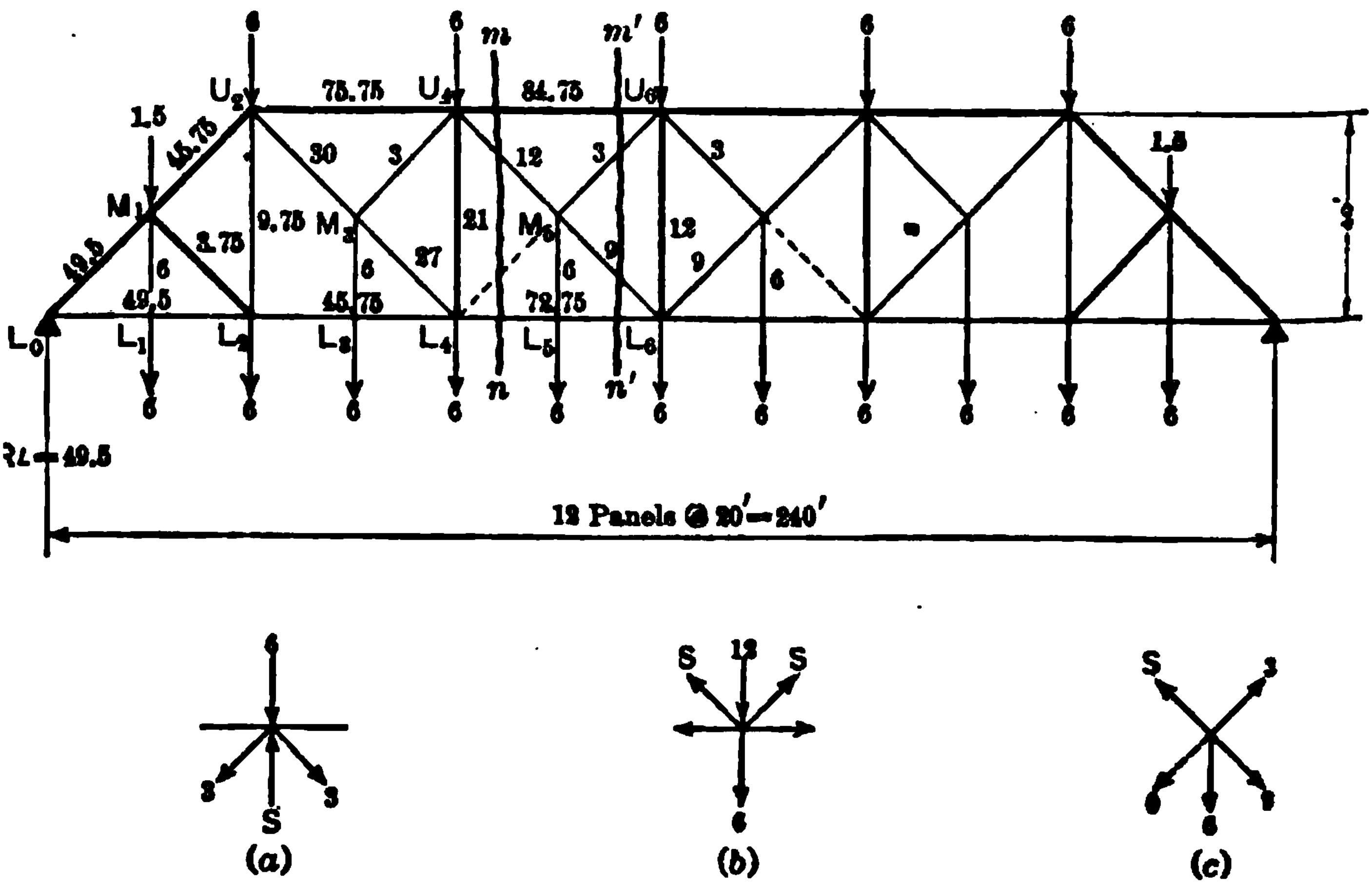


Fig. 25

panels and slope of diagonals. It may be used for spans of about the same length as for the Camel-Back truss, altho the Petit type would probably be selected in preference for spans approaching the upper limit. This is not always the case, however, as Baltimore trusses of over 300 ft in length are found. The secondary system may be arranged as in Fig. 26, and in some cases the short verticals are extended to meet the top chords and aid in supporting the dead

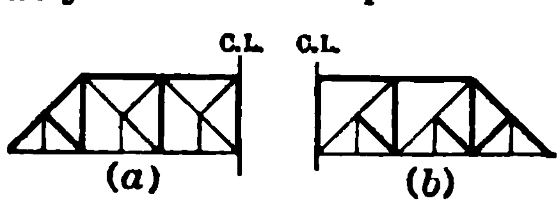


Fig. 26

load of these heavy members. Counters are required in those panels where the main diagonal may be reversed in stress by the live load. Neglecting the action of the counter $L_4 M_5$, the only way in which a bar like $M_5 U_6$ can be stressed is by the loading on L_5 in which case the stress is one-half the load. To see what effect a load on L_5 has on $M_5 L_6$, draw an influence line for vertical component of this bar (see Fig. 27). As the load of unity passes from R_R to

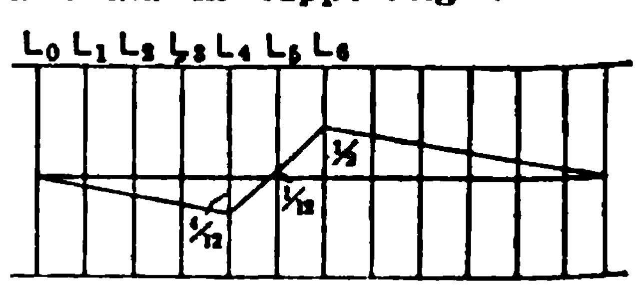


Fig. 27

L_6, the vertical component in $M_5\,L_6$ is the shear in the panel. For these loadings, $M_5\,U_6$ is not in action, and for the load at L_6 equals 1/2. When the load is on L_5 the stress in $M_5\,U_6$ is 1/2, and $R_L = 7/12$. Applying $\Sigma V = 0$ on a section thru the panel, $7/12 + 1/2 - 12/12 - S_{vc} = 0$ $S = 1/12$. With a load on L_4 the counter is in action and the stress in $M_5\,L_6$ is zero. If no counter was present the stress would show a reversal of 4/12. From an inspection of this influence line, it is plainly seen that to obtain a maximum stress in $M_5\,L_6$, the live load should be placed up to and including L_5 from the right. If the loads differed in weight, the heaviest loads should be placed as near to L_6 as possible. As a concentrated system of unequal moving loads is seldom used for highway bridge analysis, the method of determining such loading by a further use of the influence line is omitted.

Dead Load Stresses. Assume a dead load of 900 lb per ft of bridge and a live load of 1500 lb per ft of bridge. Assume the dead load distributed as shown and write index stresses. First write stresses on short verticals and short diagonals, and then take section around U_6 (see Fig. 25*a*). Apply $\Sigma V = 0$. $-6 - 3 - 3 + s = 0$. $S = 12$. Proceed to L_6 (see *b*). $-12 - 6 + 2s = 0$. $S = 9$. Proceed to M_5 (see *c*). $\Sigma V = 0$ gives $3 - 9 - 6 + s = 0$. $S = 12$. Proceed in similar manner from joint to joint as in previous trusses. Notice, in obtaining chord stresses, that $2p/h = 1$.

Live Load Stresses. Take $U_4\,U_6$. Section $m\,n$ cuts three bars only as the counter is not in action under a full load. $R_L = 5\tfrac{1}{2} \times 15 = 82.5$. Write moments about L_6, $82.5 \times 6p - 15 \times 14p - Sh = 0$. $S = 142.5$. For bar $M_5\,U_6$ take section $m'\,n'$. From a study of the influence line given in Fig. 27, it was decided to load up to L_5. $R_L = 35$. Apply $\Sigma V = 0$ on section, remembering that stress in $M_5U_6 = 7.5$. $35 - 15 + 7.5 - S_{vc} = 0$. $S_{vc} = 27.5$. For vertical $U_4\,L_4$ take a diagonal section cutting $U_2\,U_4$, the vertical, and $L_4\,L_5$. The worst possible condition for this member will occur when the bridge is loaded from the right up to L_3, omitting the load on L_4. This may be seen from Fig. 28, which is the influence line for stress in $U_4\,L_4$, considering counter $L_4\,M_5$ out of action. With this loading apply $\Sigma\,V = 0$ on the section.

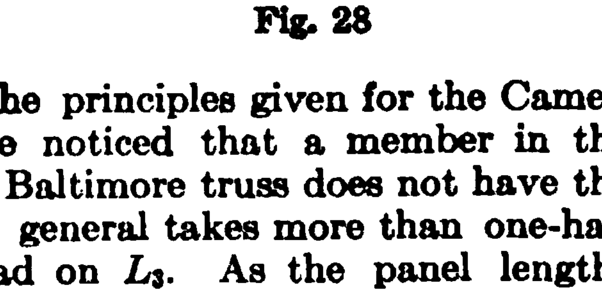


Fig. 28

Petit Truss. This truss, also called the Pennsylvania Truss, is of the Baltimore type with an inclined top chord. This truss is used for long spans. The analysis consists of the application of the principles given for the Camel-Back and Baltimore trusses. It will be noticed that a member in the Petit truss corresponding to M_3U_4 in the Baltimore truss does not have the same slope as the main diagonal and in general takes more than one-half of the load on L_3. As the panel lengths are usually equal, the vertical components of the stresses in these two diagonals may be found as follows. See Fig. 29*a*. Let $A\,C$ = load on L_3 drawn to any convenient scale. Draw $A\,B$ parallel to $U_2\,M_3$ and $C\,B$ parallel to $M_3\,U_4$, locating point B. Then $D\,B$ is vertical component of the main diagonal and $B\,E$ is vertical component of the short diagonal. This principle may be performed very quickly analytically. From the dimensions given in Fig. 29*b*:

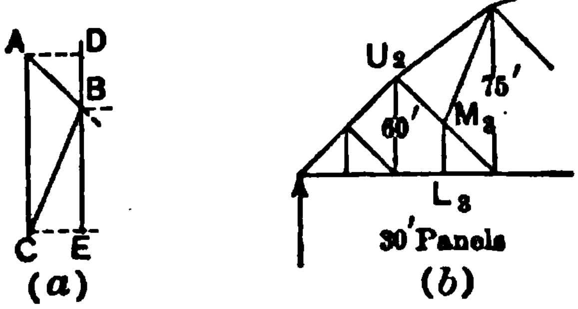


Fig. 29

$$D\,B = 30/75 \text{ of } A\,C, \text{ and } B\,E = 45/75 \text{ of } A\,C.$$

Parabolic Trusses have been used to a considerable extent in certain parts of the country for highway bridges. The two most common types

are the Sickle and the Lenticular types. The former may be either deck or thru and has the loaded chord straight and the panel points of the unloaded chord located upon the arc of a parabola. The Lenticular truss is of the thru or half thru type, and has the panel points of both chords located on the arcs of parabolas. The same principles of analysis already described apply to these trusses. The following peculiarities should be kept in mind. For a full uniform loading, the horizontal component of chord stress is constant. For this condition there will then be no stress in any of the diagonals. With equal live panel loads, placing them to obtain a maximum in the different diagonals, the horizontal component of maximum diagonal stress is constant. It is necessary to have counters in each panel. For thru bridges, the verticals will be subjected to tension under a full loading, and compression under a partial loading. By applying these principles, the truss is very simple of analysis.

Methods of Design. Tension Members are usually designed by the formula $A = P/S$, where A = net area required, P = maximum stress, S = allowable unit value of material in tension. In built-up members take account of area lost in any section by rivet holes, so that gross area will make up the loss and required net area will be obtained. In riveted trusses, tension members are usually made of angles, or channels, or a combination of plates and angles, or plates and channels. In pin-connected trusses, eye-bars are used except for members subject to a reversal of stress. It is common to make the first two panels of bottom chord of built sections for this reason. In case it is desired to obtain the stress in the bottom fiber of an eye-bar due to its own weight, to see that S is not exceeded, after having obtained size by above method, use following formula where h = breadth of bar in in:

$$S_w = \frac{4\ 900\ 000\ h}{\dfrac{P}{A} + 23\ 000\ 000\left(\dfrac{h}{L}\right)^2}$$

Compression Members are made of built sections, the most common examples being as shown in Fig. 30. Note that the dotted lines represent lattice bars. For top chords and end posts, c and f are the most common, altho a and d are sometimes used. For intermediate posts, a, b, d, and e are common. For the hip vertical, g and h are examples.

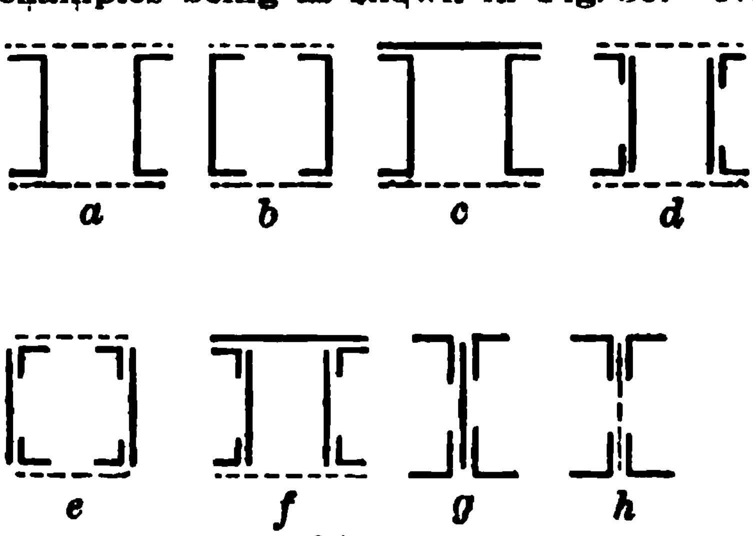


Fig. 30

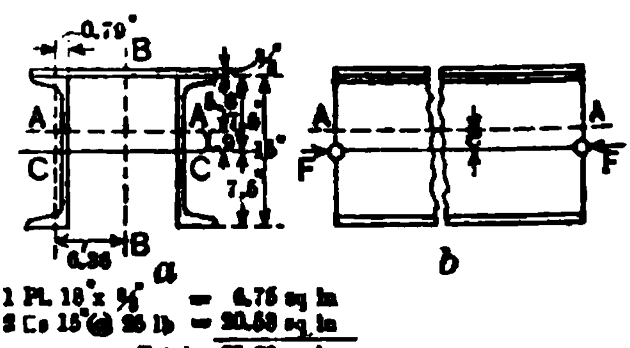


Fig. 31

Design of a Top Chord Section. Let it be required to design a top chord section whose length is 254 in for a live stress of 181 700 lb and a dead stress of 156 000 lb. For unit stresses see Specifications. Add the live and half of the dead, and use live load formula $S = 12\ 000 - 55\ L/r$.

Assume two 15 in channels and a ⅜-in cover plate. The least radius of gyration r may be assumed as 4/10 of the depth for a trial area, or 6.1. Then $S = 9710$ and $A = 259\ 700/9710 = 26.7$ sq in. Make up section as shown in Fig. 31. Find true least

radius of gyration, by obtaining moments of inertia about axes AA and BB, when $r^2 = I/A$. First locate axis AA, which is the gravity axis of the section. Take moments about lower edge of section and divide by sum of areas. $6.75 \times 15.19 + 20.58 \times 7.5 = 256.88$. $256.88/27.33 = 9.4$. $9.4 - 7.5 = 1.9$. For tabulated moments of inertia of shapes, see steel hand-books. $I_{AA} = 640 + 20.58 \times \overline{1.9}^2 + 6.75 \times \overline{5.79}^2 = 940.55$. $r^2 = 940.55/27.33 = 34.41$. $r = 5.86$. $I_{BB} = 16.96 + 20.58 \times 6.36^2 + 1/12 \times 3/8 \times \overline{18}^3 = 1032$. $r^2 = 37.76$. $r = 6.1$. Allowable unit stress $= S = 12\,000 - 55 \times 254/5.86 = 9616$. Actual unit stress $= 259\,700/27.33 = 9502$ and the area is sufficient for direct stress. The wind stress was not considered as it was less than 30% of that allowed for live and dead.

THE WEIGHT OF THE MEMBER tends to cause compression in the top fibers and tension in the bottom. The location of the pins determines the points of application of the axial forces (see Fig. 31*b*). If these points are below the center of gravity axis, there is a tendency for tension in the top fibers and compression in the bottom. It is therefore possible to place the pins at a distance e below the center of gravity axis so that these two tendencies will neutralize each other. $M = \frac{1}{8} w L^2$, where w = weight per foot. M due to eccentricity $= Fe$. If these two moments are placed equal, $e = w L^2/8F$. Conditions, such as necessary clearness for eye-bar heads, will not always allow this location, in which case the stresses caused by these two factors may be found by the following formula:

$$S_1 = \frac{Mc}{I - \frac{PL^2}{KE}}$$

S_1 = fiber stress due to cross bending. M = bending moment in inch-pounds c = distance from neutral axis to most extreme fiber on side under consideration. I = moment of inertia of section about neutral axis. P = total direct stress in member. L = length of member in inches. E = modulus of elasticity of material and K = a constant usually taken as 10 for a member having hinged ends, 24 for one end fixed and the other hinged, and 42 for both ends fixed. If P is tension, change negative sign in denominator to positive.

Design of End Post. In addition to direct stress due to live, dead and wind loads, and flexure due to weight and eccentricity, the end post is subjected to a flexure caused by a bending moment due to action of the wind on the portal bracing, which may amount to considerable. It is, however, seldom that wind stresses and live load stresses are a maximum together, and this is especially true in highway bridges. For this reason, direct wind stresses are neglected in main truss members unless they exceed a given percentage of the dead and live in the member considered, or unless they produce reversals or a bending. See Art. 4, SPECIFICATIONS. When direct or flexural wind stresses are considered, the allowable unit stress is increased by this percentage. Some specifications give this increase as 25%; Cooper gives 30%, and Ketchum allows 50% for both direct and flexural wind stresses. Some designers in computing flexure in the end post of long spans assume only half the live load with the wind load. Unless the end floor beam is rigidly connected to the end post, it is customary to consider the latter hinged at both ends, altho the following rule may be used when this condition does not exist. Multiply wind reaction at top of end post by half distance from L_0 to portal bracket and, if this is less than half the dead stress in post multiplied by distance c to c of bearings on pin, call post fixed at bottom, and take point of contra flexure half way from L_0 to portal bracket.

In order to show effect of wind on flexure, let it be required to examine the section shown in Fig. 32. Live stress including impact 185 600, dead stress 133 500. L = 256

in. Post assumed as fixed at base. Locate neutral axis. $20.58 \times 7.5 + 9 \times 15.25 = 291.6$. $291.6/29.58 = 9.9$. $I_{AA} = 319.9 \times 2 + 20.58 \times \overline{2.4}^2 + 9 \times \overline{5.35}^2 = 1016$. $r = \sqrt{1016/29.58} = 5.86$. $I_{BB} = 2 \times 8.48 + 2 \times 10.29 \times \overline{6.36}^2 + 1/12 \times \frac{1}{2} \times \overline{18}^3 = 1092$. $r = 6.08$. Assume point of contra flexure as in Fig. 32b. Direct compression due to lateral forces $= 16\,000 \times 19.17/21.5 = 14\,270$. Total direct compression $= 333\,400$. M at foot of knee brace $= 8\,000 \times 10.5 \times 12 = 1\,008\,000$ in lb. Use formula $S = 16\,000 - 70\ L/r$. $S = 16\,000 - 70\ 356/5.86 = 11\,750$. Area required for live and dead loads = 27.16 sq in. For stress due to wind moment:

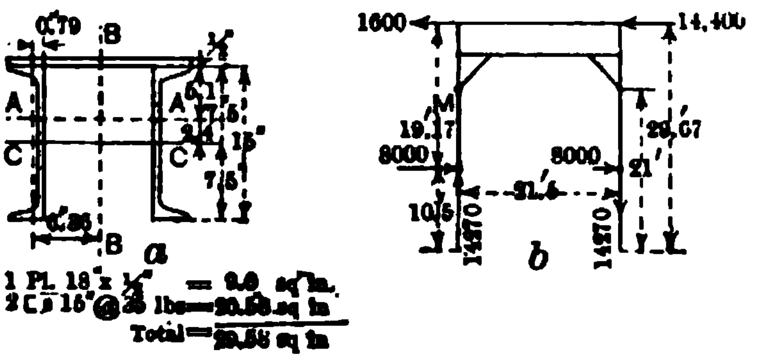


Fig. 32

$$S_1 = \frac{1\,008\,000 \times 9}{1092 - \dfrac{333\,400 \times \overline{230}^2}{24 \times 30\,000\,000}} = 8502$$

Actual fiber stress $= 8502 + \dfrac{333\,400}{29.58} = 19\,783$. Allowable unit stress $= 1.50 \times 11\,750 = 17\,625$. Efficiency = 89%. Redesign for an efficiency of 100%. The stresses due to weight and eccentricity, if desired, may be found as before indicated and combined with the above values.

Design of Intermediate Posts. The intermediate posts are designed in a manner similar to that already explained for top chord and end post. In investigating flexural stress due to sway frame brace, assume half top panel wind load as transferred into bottom lateral system thru the post.

Stringers and Floor Beams should be designed as plate girders, or if I-beams are used, they are selected as in Art. 6.

Pins are figured as a beam and should be designed for bending, shear, and bearing. Having determined the packing of the members on the pin, the horizontal and vertical components of the stresses of these members are found. Note that a maximum stress will not occur in all members at the same time and that in general two or more cases must be considered, such as (1) maximum in diagonal, (2) maximum in chord. Compute moment at center of bearing of each member on pin for both horizontal and vertical component and take the resultant for the combination which gives a maximum. Do this for each case and take largest resultant. Tables in steel handbooks will give size of pin for different allowable fiber stresses. Obtain maximum shear and determine if the pin selected is of sufficient size to withstand shear and allow a safe bearing as required in specifications. Usually built-up members, such as posts, need reinforcing plates riveted on to satisfy the conditions for bearing. Before figuring moments, it is well to determine if these plates are required by assuming the size of pin. After pins are computed, it is usual to limit them to two sizes, altho sometimes three are used.

Camber. The deflection of a beam or truss under its own weight and the loads which come upon it is caused by the elastic properties of the material and by imperfect workmanship. In short spans, the deflection is not important, but in spans of average or considerable lengths it should be taken into consideration. This is especially true in pin-connected bridges, where there must be more or less play in the joints. It is usual, in all except short spans, to provide a camber by making the top chord slightly longer than the bottom chord, in order that the truss shall assume

its theoretical form when fully loaded. The most common method in highway bridges is to make the lengths of the top chord panels longer than the bottom chord panels by 3/16 in for every 10 ft. This method, while empirical, gives good results in most cases. If it is necessary to use more refined methods, as might be the case for extra long spans, cantilevers, and draw spans, the deformations may be figured, and the tension members decreased and the compression members increased in length accordingly. For the more exact methods, consult references.

7. Timber Highway Bridges

Wooden Beams are designed by the formula $M = SI/C$, where M is the maximum bending moment, I, the moment of inertia of the section about the neutral axis, and C, the distance from the neutral axis to the most strained fiber. For the usual case, a wooden beam is of rectangular shape and of constant cross-section. For this condition, $I = 1/12\ b\,h^3$ and $C = h/2$. The above formula reduces then to $M = Sbh^2/6$. Beams which are unusually short and deep should then be investigated to see that the safe longitudinal shearing strength is not exceeded. If s is longitudinal shear per sq in, V is external shear, and A area of cross-section, then $s = 3\ V/2\ A$. It is usually only necessary to obtain the bending moment M, and select the safe working value S for the timber used, and figure $b\,h^2$, from which the dimensions may be selected to conform to commercial sizes. For working unit stresses see Sect. 2, Art. 5.

Wooden Columns are designed by the use of a column formula. See table in Sect. 2, Art. 5.

Trussed Beams are used when the span length becomes too great for an efficient use of simple beams. This limit is about 20 ft. There are two types, the King Post and the Queen Post (see Figs. 33 and 34). The King Post is used for spans from about 20 ft to about 25 ft, and the Queen Post for spans over 25 ft. Each may be used as a deck bridge, instead of thru as shown. In case of the deck structure, it should be noted that the inclined members become tension pieces and the vertical members compression pieces, and that the beams become the top instead of the bottom chord. The beam is usually one timber, or two or more timbers bolted together, extending over the entire span, and is therefore subject to continuous beam action. In designing such a structure, it is common to find the stresses on the assumption that the members together act as a truss, and add to the unit stress in the beam due to this action, the bending unit fiber stress due to direct loads. In the thru structure, the top chord, including the inclined members, are timbers, and the verticals are rods. In the deck structure, the bottom chord is usually one or more rods and the verticals become timbers. Care should be taken to make suitable joints at the intersection of timbers and to use washers and plates, or cast-iron caps, of sizes sufficient to transmit stress without producing too great unit pressure on the wood. If the floor of the bridge is supported directly upon the chords, as would be the case in a deck structure, the load becomes uniformly distributed and the beam is subjected to a cross bending in addition to the stress due to truss action. If the floor rests upon joists, which in turn are supported by beams at points a, the load becomes concentrated and the only cross bending is due to the dead weight of the beam which under usual conditions may be neglected. The following formulas are sufficient for practical purposes.

King Post (see Fig. 33), UNIFORM LOAD. Let w = load per ft, + = tension, and − = compression. $ab = +5.8\,w\,L$, $cb = -w\,L\,m/2\,h$, $ac = +w\,L^2/8\,h$. Unit stress in $ac = +w\,L^2/8\,b\,d\,h$, and to find total unit stress add to this the greatest fiber stress due to cross bending obtained by the formula $S_1 = +2.25\,w\,L^2/b\,d^2$. CONCENTRATED LOAD of W at a: $ab = +W$; $cb = -W\,m/2\,h$; $ac = +W\,L/4\,h$.

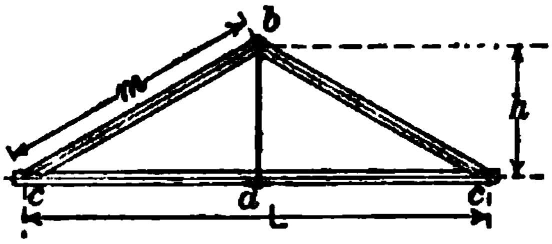


Fig. 33

Queen Post (see Fig. 34), UNIFORM LOAD. $ab = +11/30\,w\,L$; $cb = -w\,L\,m/3\,h$; $cc = +w\,L^2/9\,h$, $bb = -w\,L^2/9\,h$. Unit stress in $cc = w\,L^2/9\,b\,d\,h$, and to find total unit stress add to this $S_1 = +w\,L^2/b\,d^2$. CONCENTRATED LOAD of $W/2$ at points $a\,a$: $ab = +W/2$; $cb = -W\,m/2\,h$; $cc = +W\,L/6\,h$; $bb = -W\,L/6\,h$.

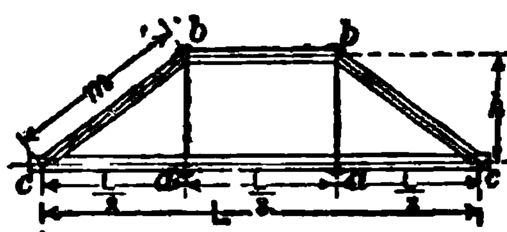


Fig. 34

Timber Bridges of the Howe Type (see Fig 35), altho formerly very common in certain sections, are not now built except in special cases, such as for temporary traffic, falsework, etc. These bridges are usually covered by a roof and sides to prolong their life. Many are in existence in New England rural sections, but they are gradually being replaced by steel bridges or concrete arches. The chords and diagonals are made of timbers and the verticals of rods. The stresses may be figured in the same manner as for the Pratt truss, which see. Usually counters of timber are placed in each panel, the same as shown in the figure for the two center panels.

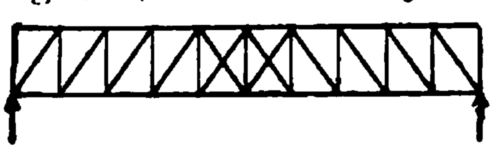


Fig. 35

8. Highway Bridge Floors

Width of Roadway. See also Art. 4, CLEARANCES. The width of roadway for a highway bridge is much more variable than for a railroad bridge. In general there is little variation in the clear width of the latter, the chief factor being the number of railroad tracks to be accommodated. The width of a highway bridge depends upon the volume of traffic, which in turn regulates the kind of wearing surface; the latter regulating the floor, or supports for the wearing surface. Thus a country bridge designed for loads under Art. 4, COOPER CLASS D, would probably have a floor of simple construction, such as plank, resting directly upon stringers, with a clear width of not less than 12½ ft, while if CLASS C were used, the width would be at least 14 ft. If it is desired to have vehicles pass each other on the bridge, these figures must be increased. Good practice inclines toward bridges of greater widths than these figures. The length of span must also be taken into consideration. Ketchum and the Mass. R. R. Comm. require the width between *c* to *c* trusses to be at least 1/20 span length, and the former, preferably, at least 1/12 span length.

CITY BRIDGES which carry almost constant traffic, must have a wearing surface of more durable material than plank. This requires a different arrangement of the floor system, and a width sufficient to take care of the traffic in both directions. This does not mean that it is necessary to have the same width as the city streets for traffic over a bridge is continuous, there being no necessity for stopping at the curb. There should be no difficulty in selecting a width of roadway in the case of country bridges, with or

without electric cars. For the case of suburban or city bridges, the case may call for study. The following data by Spofford (68b) will be of interest.

Horse-Drawn Vehicles. The width of ordinary horse-drawn vehicles as measured in the streets of Boston is given in the following table, in which (1) represents distance, in feet, out to out of hubs; (2) the distance, in feet, out to out of wheels; (3) the distance, in feet, out to out of whiffletrees:

	(1)	(2)	(3)
Hay wagon	7.75	7.00	8.00
Heavy express	7.65	6.70	7.90
Heavy express	7.80	6.70	7.60
Ice wagon	7.40	6.60	7.00
Hack	6.08	5.25	6.83
Coal wagon, 3-horse	8.50	....	10.83

Electric Cars. In comment upon the widths of electric cars, it may be noted that the Mass. Public Service Comm. specifies that the distance center to center of tracks, should be 9.71 ft, and that for this spacing a total width in the clear of 18.5 ft is required by two lines of the widest cars, 8.79 ft in width, used in Boston.

Width of Various Bridges with Traffic Statistics. Brooklyn Bridge. Width of roadway, two roadways 16 ft 9 in each between curbs, with single street-car track on each. Traffic in 1912, surface cars, round trip, 1 474 610; average per day, including Sundays, 4029 single trips; other vehicles, exclusive of trains, 1 282 000; average per day of 24 hr, including Sundays, 3503 single trips.

Manhattan Bridge. One roadway 35 ft between curbs, without street-car tracks in roadway. Total roadway vehicle traffic in 1912, 1 607 800; average per day, including Sundays, 4381 single trips.

Congress Street Bridge, Boston. One roadway 44 ft between curbs on fixed spans; 31 ft 4 in between curbs on draw-span. This bridge, including draw-span, is used regularly by three lines of vehicles, and can be used by four lines. No street cars. Traffic on Sept. 11, 1908, 7362 vehicles.

Rush Street Bridge, Chicago. Two roadways 17 ft 4 in between curbs. Two lines of traffic on each roadway. Traffic on Feb. 4, 1915, between 7 A.M. and 7 P.M. consisted of 11 594 horse-drawn and motor vehicles.

The following figures are from the 1911 Report of the London Traffic Branch of the Board of Trade and refers to traffic on 1 day in 1911, between 8 A.M. and 8 P.M.:

Waterloo Bridge. Width of roadway in the clear, 27 ft 6 in; 10 192 horse and motor vehicles; no street-cars.

Westminster Bridge. Width of roadway in the clear 54 ft; 14 618 horse and motor vehicles, including 2975 electric tram cars.

Blackfriars Bridge. Width of roadway in the clear, 73 ft 6 in; 14 067 horse and motor vehicles, including 1829 electric tram cars.

London Bridge. Width of roadway in the clear, 37 ft; 13 771 horse and motor vehicles; no street-cars.

Weighted Traffic Units. In order to accurately measure the capacity of a bridge or street in relation to traffic, it is evidently necessary to consider the character of the vehicles and their speed, as well as their number. For the purposes of making such a comparison, the London Board of Trade sets up as a unit a motor-cab or carriage, and assigns the following numbers to other classes of vehicles:

Trade Vehicles		Passenger Vehicles	
1 Horse, fast	8	Electric trams	10
1 Horse, slow	7	Omnibuses, horse	5
2 Horse, fast	4	Omnibuses, motor	3
2 Horse, slow	10	Cabs, horse	2
Motor, fast	2	Cabs, motor	1
Motor, slow	5	Carriages, horse	2
		Carriages, motor	1
		Barrows	6
		Cycles	½

The Board lays down the following definitions.

TRAFFIC VOLUME at a point is the average aggregate number of traffic units attributable to vehicles which pass it per min during the 12 hr from 8 A.M. to 8 P.M.

AVERAGE TRAFFIC DENSITY is the aggregate number of traffic units attributable to vehicles, which pass the point during the 12 hr, per min, per 10 ft of available carriageway.

GREATEST TRAFFIC DENSITY is the average density per min, per 10 ft of available carriageway, during the busiest hour, expressed in traffic units.

With the above units and definitions in mind, the following comparison of traffic on London bridges is clear:

	Westminster Bridge	Waterloo Bridge	Southwark Bridge	Blackfriars Bridge	London Bridge
Traffic volume	90.4	60.5	105.9	16.6	89.2
Average traffic density	20.8	22.0	14.4	5.8	24.1
Hour of greatest density	6 to 7	5 to 6	6 to 7	....	11 to 12
Density of that hour	23.8	22.5	15.3	....	27.4
Average vehicles	4.2	3.9	5.0	4.1	4.0

Wearing Surfaces and Their Supports. See Art. 4, FLOORS. The surfaces most commonly used are plank, wood block, stone block, and brick. Sheet-asphalt, bituminous pavements, and cement-concrete are also used under special conditions. Drowne (41) in a report to the 3rd Int. Road Cong., 1913, concluded that " If the support furnished the surface is unyielding. the wear of bridge surfaces of wood block, sheet-asphalt, stone block, brick and other similar types is not any different than it is under the same conditions on the street."

PLANK is used mostly for country bridges and may be of one thickness or two. The life of a plank floor is very variable, depending chiefly upon the amount and kind of traffic, and also upon the wetness of the seasons. This variation will be from a few months, if used near a city, to several years if in a place where travel is very light. Spruce is the most common plank altho yellow pine, Douglas fir, oak and chestnut are used. The planks may be laid either at right angles with the axis of the bridge or diagonally, the latter method making a floor which will be much stiffer. Planks should not be laid lengthwise of the bridge except under special conditions. They should usually be laid with the heart side down. A plank floor is supported upon steel or wooden stringers, spiking pieces being bolted to the steel stringers. It is not customary to crown a single plank floor, but if two thicknesses are used, a crown is more necessary.

WOOD BLOCK PAVEMENTS are in use in the more thickly settled districts. The blocks are usually about 3 or 4 in square and 6 to 10 in long and should always be treated with preservatives. They are usually laid upon a cushion of sand, asphalt, cement mortar or tar pitch resting upon a sub-base of wood or concrete. The wooden base is usually from 3 to 6 in in thickness and is either treated with preservatives or water-proofed in some way, and the joints made tight. The concrete base is usually supported by a buckle plate floor or by a reinforced concrete slab floor, or by concreting between I-beams. A longitudinal expansion joint 1 or 2 in in width should be provided next to the wheel guard.

STONE BLOCK PAVEMENT is durable but expensive, and very heavy. It is used when traffic is extremely heavy. It is laid on a cushion

of sand, and should have the joints filled with tar pitch. A concrete base is a common method of support altho sometimes the wooden base is used. Stone makes a much better foothold for horses than the other surfaces.

BRICK PAVEMENT is much lighter and less noisy than stone and is cheaper than wood block pavement. The method of laying is similar to wood-block.

CEMENT-CONCRETE may be used directly as a wearing surface. Its construction will be obvious. Sometimes a concrete surface is protected by a bituminous surface coating.

Specifications. Altho Art. 4 gives an outline of several specifications which include floors, the following paragraphs, being more complete in themselves, give further data.

Wooden Joists. Wooden floor joists shall be spaced not more than 2½ ft centers, and shall lap by each other so as to have a full bearing on the floorbeams. Their width shall not be less than 3 in, or ¼ the depth of joist. When spaced not more than 2 ft centers, one joist shall be considered as carrying ½ of the concentrated live load.

Steel Joists. Steel beams when used as joists shall have a depth of not less than 1/30 of the span, and 1/20 of the span when used as track stringers. When a single thickness of plank flooring is used the spacing of steel joists shall not exceed 2 ft 6 in, centers; when a heavier floor is used this limit may be 3 ft. When spaced not to exceed 2-ft centers, one joist shall be considered as carrying ½ the concentrated load; when spaced more than 2 ft and not more than 3 ft, one joist shall be considered as carrying ⅔ of the concentrated load.

Floor Beams. All floor beams shall be rolled or riveted steel girders, rigidly connected to the trusses at the panel points, or may be placed on the top deck bridges at panel points. Floor beams shall preferably be square to the trusses or girders.

Connections. All steel joists and stringers shall preferably be attached to the floor beams by means of connecting angles, altho in ordinary country bridges of CLASS D the joists may be decked on top flange of floor beams. In case shelf angles, stiffened with vertical angles, are used, the rivets in such angles and stiffeners may be counted as carrying end shear.

Solid Floor. For city and suburban bridges, a solid floor, consisting of wooden blocks, brick, stone blocks, sheet-asphalt, etc, on a concrete bed, is recommended. For this case the floor shall consist of buckle plates or corrugated sections or other satisfactory reinforcement, and a waterproof concrete, bituminous or Portland cement mortar, bed not less than 3 in thick for the roadway and 2 in thick for the footwalk, over the highest point to be covered, not counting rivet or bolt heads. The floor shall be laid with a slope of at least 1 in in 10 ft. Buckle plates shall not be less than 5/16 in thick for the roadway and ¼ in thick for the footwalk. The crown of the plates shall not be less than 2 in. For solid floor the curb holding the paving and acting as a wheel guard on each side of the roadway shall be of stone or steel projecting about 6 in above the finished paving at the gutter. The curb shall be so arranged that it can be removed and replaced when worn or injured. There shall also be a metal edging strip on each side of the footwalk to protect and hold the paving in place. Pavements consisting of wooden blocks may rest upon a wooden floor, consisting of planks laid transversely and at least 4 in thick. The type of block and method of laying shall be approved by the engineer.

Plank Floor. For single thickness the roadway planks shall not be less than 2½ in thick for oak, southern yellow pine and chestnut or 3 in for white pine, spruce and Douglas fir, nor less than 1/12 of the distance between centers of joists, and shall be laid transversely with ¼-in openings and securely spiked to each joist. All plank shall be laid with heart side down. When an additional wearing surface is required, it shall be 1½ in thick, and the lower planks of a minimum thickness of 2½ in shall be laid diagonally with ½-in openings. Footwalk plank shall be not less than 2 in thick nor more than 6 in wide, spaced with ½-in openings. All plank shall be laid with heart side down, shall have full and even bearing on and be firmly attached to the joists, and shall be sawed in a straight line along the outside of roadway and walk.

Wheel Guards. Wheel guards of a cross-section of not less than 6 by 4 in shall

be provided on each side of the roadway. They shall be spliced with half-and-half joints with 6-in lap, and shall be bolted to the stringers or joist with ⅝-in bolts, spaced not to exceed 5 ft apart.

Wood Block Paving shall be laid on a plank base, secured to spiking pieces; all of which shall be of sound merchantable southern yellow pine, free from loose or unsound knots or other imperfections which would impair its strength or durability. All to be cut from sound live trees. The spiking pieces if laid on top of joists will be 6 in in width and not less than 4 in in depth. The under course of the floor will be of 3 in plank sized to an even thickness of not less than 2⅞ in and laid with close joints. All unavoidable openings to be thoroly calked with oakum or other suitable material. Upon this base will be laid the wood block paving .... inches in depth.

The PAVING BLOCKS will be truly rectangular in form and shall be dressed on all sides except the top and bottom, both of which shall be smoothly sawn. The blocks shall not vary in width or depth more than 1/16 in. Their width shall be the same for the entire job and must not be less than 3 nor more than 4 in. Their length shall not be less than 6 nor more than 10 in.

TREATMENT. The spiking pieces, planking and track ties shall be creosoted with 12, and the paving blocks with 18 lb of dead oil of coal tar per cu ft of lumber, injected by the pressure process in closed cylinders. The creosote oil shall have a specific gravity between 1.03 and 1.07 at 38° C (100° F). The blocks when ready for use shall not absorb water more than an average of 4½% of their dry weight after being heated at 38° C (100° F) during 12 hr and then placed under water 12 hr.

CONSTRUCTION. The blocks will be set on a cushion consisting of a heavy coat of coal tar paving pitch applied while hot to the planking. They must be set and tamped quickly before the pitch hardens. The joints must then be thoroly pitched and the surface flushed with an application of the hot paving pitch, until all joints are completely filled. The blocks will be set with the grain vertical and with close joints and in uniform courses at right angles to the center line of the bridge, in such a manner that the longitudinal joints will be broken at least 2 in. They must be forced together as close as possible by hand when laid and properly tamped to a firm bearing and uniform surface. An expansion joint of such width as directed by the engineer will be provided next to the wheel guards. The expansion joint to be finally filled with the paving pitch. A thin layer of dry sand will be spread over the finished surface if required by the engineer.

9. Reinforced Concrete Beam and Girder Highway Bridges

Reinforced Concrete Beam Bridges may be divided into two classes. First, those bridges of short span, not exceeding about 20 ft, and having only ordinary country highway traffic, which are reinforced concrete slabs bearing from 12 to 18 in on each abutment. Such slabs may be designed the same as the tops of reinforced concrete box culverts. The Connecticut standard design for this type of bridge for 16-ft span is shown in Fig. 36. The second class is made of similar reinforced concrete slabs, but bear not only on the abutments, but also on two or more reinforced concrete beams which in turn bear also on the abutments. The beams in this case are not loaded uniformly thruout their clear span. If the clear span of the beam is at least 1.5 times the clear distance between the beams, the maximum bending moment may be taken as if the beam were uniformly loaded and is found by the formula $M = wL^2/8$ where w is the load in pounds per foot and L is the clear span in feet. For less span of beam use the formula: $M = \frac{wL^2}{8}\left(1 - \frac{1}{3}\frac{L_s^2}{L^2}\right)$, where L_s is clear distance between beams. This result should be multiplied by 12 to get M in inch-pounds. To obtain the dimensions of the beam, a simple approximate formula is $bd^2 = M/100$, where b is the width of the beam, and d is the depth from the top of the beam to the middle of the reinforcing steel. Both b and d are in inches. A value for either b or d must be assumed and then the formula solved for the other.

Usually b should be about ½ to ⅔ as great as d. As d is depth to the steel, the total depth of the beam should be about $d + 1\frac{1}{2}$. The reinforcing steel is made up of round steel rods whose diameter is from ½ to 1 in. The

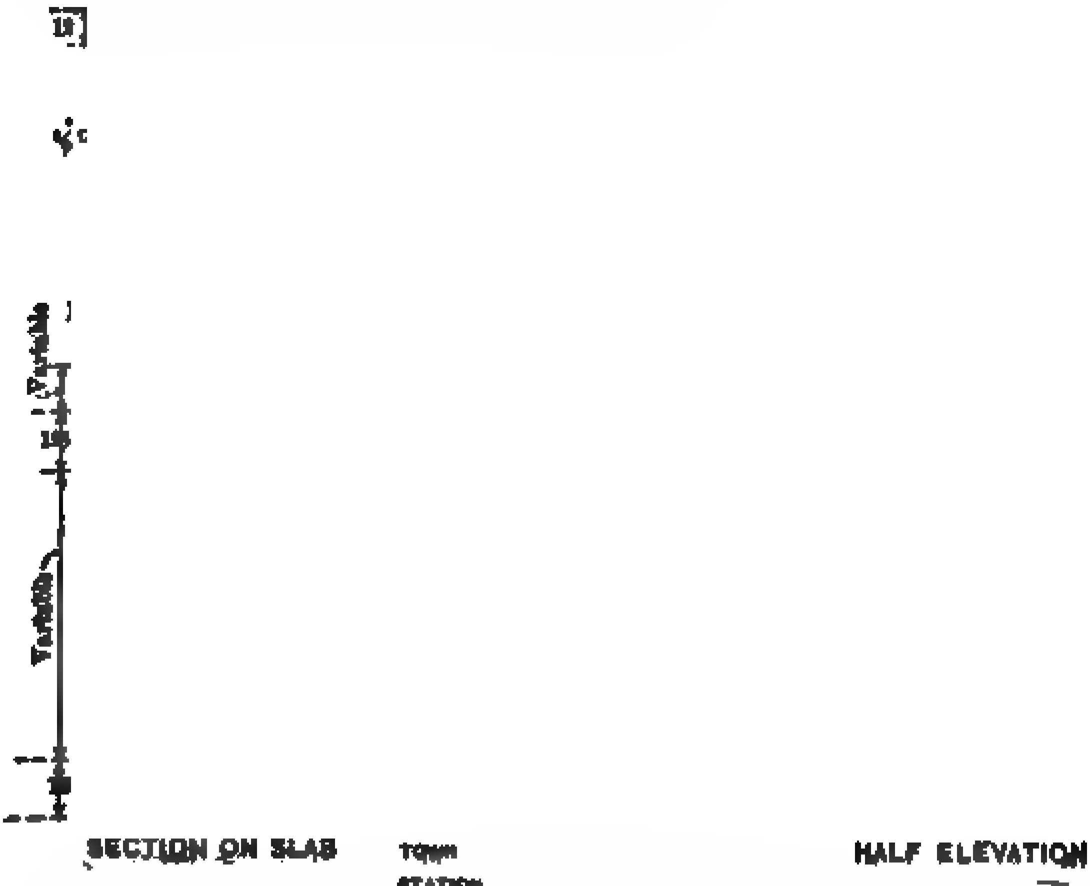


Fig. 36

total area of steel in the beam should be about $bd/100$. The rods may be spaced from 2 to 6 in center to center. Unless the clear span of the beam is at least 100 times the diameter of the reinforcing steel, twisted square rods should be used in place of plain round rods. About ⅓ of the rods in a

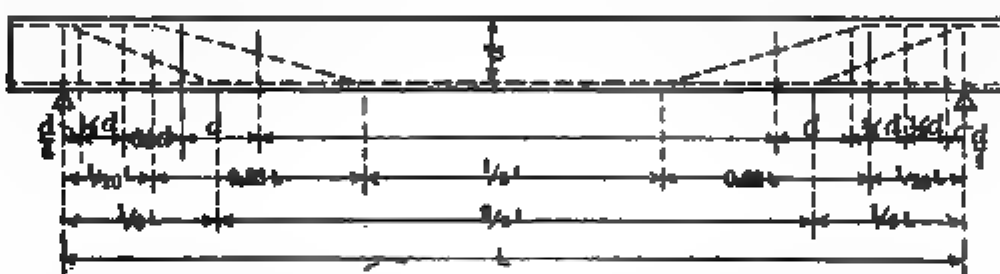


Fig. 37

beam or slab may be left horizontal thruout their entire length Half of the remainder should be bent up near the supports according to each of the two sets of dimensions in Fig. 37. The reinforcement is bent up at an angle of 30° to 45° until it reaches a point about 1 in from the top of the

beam, and then it is carried horizontally for the rest of its length. This diagonal reinforcement takes part of the diagonal tension resulting from vertical and horizontal shear. In addition to bending the rods, it is good practice to reinforce against diagonal tension by the use of stirrups. Stirrups are usually made of round or square steel rods about half the size of the longitudinal reinforcing bars. These rods are bent into complete rectangles, the ends being welded together. The dimensions of the rectangle are such that they will just surround the longitudinal and bent bars, that is they will be from 1 to 2 in inside of the surfaces of the beam. The stirrups should be wired firmly to the longitudinal bars. One stirrup is placed at a distance ¼ *d* from the support; the second ½ *d* from the first; the third ¾ *d* from the second; and the fourth *d* from the third (see Fig. 37). The reinforcing steel of a slab bearing on all four edges must be divided between the two directions. If, however, one dimension of the slab is more than 1½ times the other, the slab should not be considered as bearing on the ends of its long dimensions, but may be designed as a simple slab having a span equal to its shorter dimension. If the slab is square, ½ of the load is considered as carried by each set of reinforcement.

Taylor and Thompson (20) give the following table for the ratio of load carried by the shorter span:

Ratio of Length to Breadth of Slab	Ratio of Load Carried by Shorter Span	Ratio of Length to Breadth of Slab	Ratio of Load Carried by Shorter Span
1.00	0.50	1.30	0.80
1.05	0.55	1.35	0.85
1.10	0.60	1.40	0.90
1.15	0.65	1.45	0.95
1.20	0.70	1.50	1.00
1.25	0.75		

In case a slab or beam is continuous over three or more supports, the maximum [bend]ing moment will come over an interior support, and may be taken as $M = wL^2/12$, and tension will exist in the top of the slab at these points which must be provided for in the reinforcing.

Several Girder Spans may be used in place of a long steel bridge where the necessary piers would not result in a serious obstruction in the river bed. For principles of design, see Sect. 2, Art. 3, REINFORCED CONCRETE. For design of beams reinforced both top and bottom, see (20) and (21). They may also be used where arches would be impracticable on account of lack of the rigid foundations so necessary in arch construction. An investigation carried on by the Ill. Highway Comm. on a 40-ft thru girder concrete bridge shows that there is a great increase in rigidity of such structures. When the structure was over 3 years old, it took twice the load to produce the same deflection as at age of 90 days. It should be noted that in the design of reinforced concrete bridges, the dead weight may be several times that of the live load, and that the latter may cause very little proportional increase in stress in the materials. The 4th Report of the Ill. Highway Comm. calls attention to the following:

"The abutments for slab bridges are usually low and comparatively rigid, and as it has been found impracticable to provide sliding of the superstructure over the abutments, it has been found more economical for slab bridges to provide sufficient steel to take care of the combined dead load, live load and temperature stresses than to provide a more or less complicated and expensive expansion of low friction. In the

design of reinforced concrete girder bridges, however, it has been found more economical to provide for expansion at one end of the bridge than to use sufficient reinforcing steel to take care of the temperature stress in addition to the dead load and live load stresses. The use of an expansion device of low friction justifies the use of a higher dead and live load unit stress in the steel. This is of considerable importance particularly for long span reinforced concrete girders where the space available for packing the girder steel is limited. Two methods of providing for expansion in girder bridges have been used and both have proved satisfactory. (1) In this method, the wing walls of one abutment are entirely separated from the abutment wall proper, the latter being free to move at the top with the expansion or contraction of the superstructure. The wing walls are designed to be self-supporting. As girder spans designed by the Commission have so far been limited to 60 ft, the amount of movement either way from the normal is small and is taken up by deflection of the main wall or a slight rocking of the wall on the footing. (2) The present method of providing for expansion is to design the abutments and wings in the ordinary way, separating the superstructure completely from one of the abutments by a thick paper joint and supporting each girder at the free end on a single cast iron rocker of large diameter. The reaction is transmitted to the girder and abutment from the rocker thru planed structural steel plates stiffened with I-beams when necessary. The rocker surfaces in contact with the bearing plates are turned to insure perfect bearing on the plates. The diameter of the rocker is made proportional to the load imposed per lineal inch, in the same manner as is commonly used in proportioning roller nests for steel bridges. The upper and lower plates are bedded in the concrete of the superstructure and abutments. The rocker is located in a pocket built in the abutment. This pocket is filled with a soft asphalt to prevent the entrance of water or dirt and to protect the metal from corrosion. The rocker method of providing for expansion has proved very satisfactory, and is but little more expensive than the other method."

10. Reinforced Concrete Arch Highway Bridges

Types. There are two general types of reinforced concrete arch bridges, the spandrel filled arch and the open spandrel arch. In the spandrel filled arch the ring is continuous for the full width of the arch and the load on the rib is the weight of paving, earth fill, the rib itself, and the live load. The open spandrel arch may be built with a continuous arch rib or with two or more separate ribs, and the load is transferred either by columns or walls when the rib is continuous and by columns when there are separate ribs. In the open spandrel type, the bridge floor is usually the ordinary girder and slab construction, and is designed by the usual methods of reinforced concrete, namely, for its own dead weight, the weight of paving and fill and the specified electric car or road roller concentration. The rib is usually designed for an equivalent uniformly distributed load unless the span is so small that the concentrations of the moving load cause a worse condition. The typical problem which follows deals with an open spandrel arch. The spandrel filled arch is computed in the same way except a slice of arch 1 ft wide is used and all loads are for this width. Loads in this case are conveniently considered to act at center of divisions.

Shape of Arch Rib. The curve of the rib may be anything that fits the line of pressure. It is usually circular, three or five-centered, elliptic or even parabolic. The circular curve is usually satisfactory for open spandrel arches and the three-centered and elliptic curves are common and satisfactory for spandrel filled arches.

Loads. The dead load is the actual weight of the structure based on 150 lb per cu ft for reinforced concrete and 100 to 120 lb per cu ft of fill plus the weight of paving and track. Suitable live loads depend upon the location of the structure, city, suburban or country, and whether the bridge carries electric cars. All highway bridges should be designed to

carry a road roller. Equivalent uniformly distributed live loads for the arch ribs of highway bridges carrying electric cars as well as the loads on roadway and sidewalk are shown in Fig. 38 by Taylor and Thompson (20). Live loads for floors and columns are shown in Fig. 39.

Impact. There is no unanimity of opinion as to the proper impact allowance for highway arch bridges. It seems proper to vary the impact stress from zero in light country bridges without electric cars to not more than 50% in heavy city bridges with electric cars. A common formula is $I = S\dfrac{150}{300 + L}$ in which S = live load effect, due to moment, shear or stress; L = loaded length producing maximum effect; I = impact effect. Impact is more important upon the floor than upon the ribs.

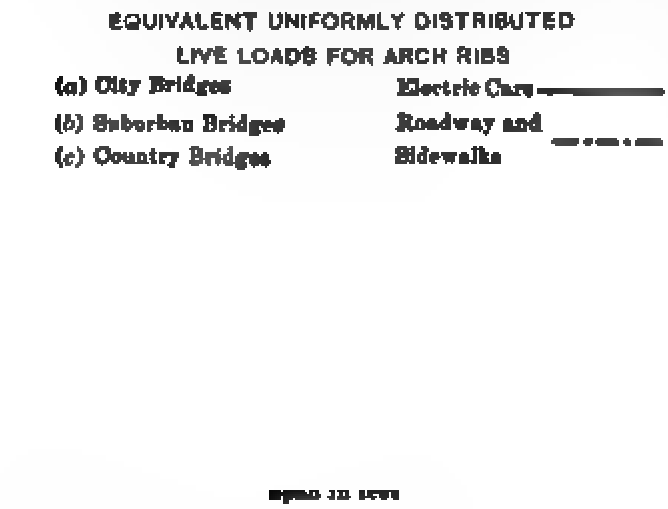


Fig. 38

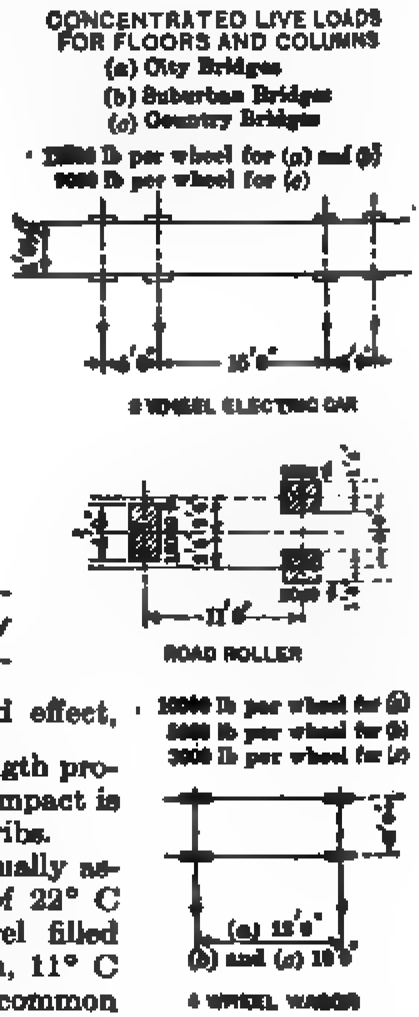


Fig. 39

Temperature. Open spandrel arches are usually assumed to have a variation of temperature of 22° C (40° F) above and below the mean. Spandrel filled arches are not subject to so large a variation, 11° C (20° F) above and below the mean being a common assumption. These figures apply in the northern part of the United States. If temperature stresses are not computed, the dead and live load compression stress in the concrete ought to be limited to about 500 lb per sq in.

Rib Shortening. Stresses due to rib shortening are similar to those due to a fall in temperature, and it is usually not necessary to compute them except in very flat arches. In a rib with ratio $\dfrac{\text{span}}{\text{rise}} = 5$, the effect is about 30% of that due to fall in temperature of 11° C (20° F) or 15% due to a fall of 22° C (40° F).

Materials. First-class 1 : 2 : 4 broken stone concrete ought to be used for all concrete above foundations. In many cases abutments or foundations may be 1 : $2\frac{1}{2}$: 5 or 1 : 3 : 6 concrete.

Unit Stresses. The unit stresses recommended by the Joint Committee on Concrete and Reinforced Concrete (24) are satisfactory for the slabs, beams and columns of open spandrel arch bridges. This Joint

Committee was composed of 28 representatives from the Am. Soc. C. E., the Am. Soc. Test. Mat., the Am. Ry. Eng. Assn., the Assn. Am. Portland Cement Mnfrs. and the Am. Concrete Inst. The recommendations of this Committee for allowable working stresses on plain and reinforced concrete are made in percentages of the ultimate compressive stress, developed in 28 days on cylinders 8 in in diameter and 16 in long. The recommended unit stresses for a 1 : 2 : 4 concrete, developing an ultimate compressive stress in 28 days of 2000 lb per sq in, are as follows:

Intensities of Working Stresses for Reinforced Concrete

Kinds of Stress	Percentage of 2000 lb	In Pounds per Square Inch
Compression on concrete in extreme fibres of beams	32.5	650
Compression on concrete in extreme fibres of continuous beams at supports	37.5	750
Concentric compression on a plain concrete pier, the length of which does not exceed four diameters	22.5	450
Bearing on plain concrete applied to a surface whose area is at least twice that of the loaded area	35.0	700
Concentric compression on a column reinforced with not less than 1% and not more than 4% of longitudinal bars only, the length of which is less than 12 diameters	22.5	450
Concentric compression on columns reinforced with not less than 1% and not more than 4% of longitudinal bars and with circular hoops or spirals not less than 1% of the volume of the concrete and in which $l/d=10$. (The effective area of a hooped column is the area within the circle enclosing the spiral hooping)	35.0	700
Punching shear on footings	6	120
Shear on concrete in beams with horizontal reinforcement only	2	40
Shear on concrete in beams with varying kinds of web reinforcement	4.5 to 6	90 to 120
Bond stress between concrete and plain bars	4	80
Bond stress between concrete and deformed bars	5	100
Bond stress between concrete and drawn wire	2	40
Tension and compression on steel in reinforcing bars		16 000

The Joint Committee makes no recommendations for working intensities of stress on plain or reinforced concrete arch ribs. The usual specifications give the following values for highway bridges: Compression on concrete in extreme fibers of arch ribs when live and dead loads only are considered, 500 lb per sq in. Compression on concrete in extreme fibres of arch ribs when stresses due to dead and live loads, temperature and rib shortening are considered, 600 per sq in. These two values are, however, seldom consistent inasmuch as stresses due to temperature and rib shortening are frequently much larger than the difference of 100 lb.

Temperature stresses vary a great deal in different arches so that the omission of such stresses can not be recommended. It is better practice to compute the stresses due to the dead and live loads, temperature (40° F

in northern part of the United States) and rib shortening, in which case it is believed that ribs having $l/d = 10$ can properly be designed by using a maximum compressive working stress of 700 lb per sq in. l = unstiffened length of rib and d = smallest transverse dimension of rib. If both impact and temperature stresses are considered it is permissible to use $f = 750$ lb per sq in compression in 1 : 2 : 4 broken stone concrete.

Position of Live Load for Maximum Stresses in Arch. For the rib itself, approximately the worst position is when half the bridge is covered with live load. This is due to largely increased moments. In a series of arches the worst condition of loading for a pier occurs when the longer span is covered with live load and the shorter one carries dead load only.

The Method of Design outlined below is the ELASTIC METHOD adopted to fixed ends since the great majority of concrete arches are of this type. For derivation and full discussion, see Turneaure and Maurers' Principles of Reinforced Concrete Construction (21).

Approximate Thickness of Arch Rib at Crown. It is convenient to start the design knowing the approximate thickness of the arch rib at the crown. A common formula is given by F. F. Weld, applying to spandrel filled arches only, as follows: $d = \sqrt{L} + 0.1\,L + 0.005\,W + 0.0025\,D$, in which d = depth of arch rib at crown in inches, L = clear span in feet, W = live load in pounds per square foot uniformly distributed, D = dead load of material above the crown of the arch per square foot in pounds. The arch rib is ordinarily from one and one half to twice as thick at

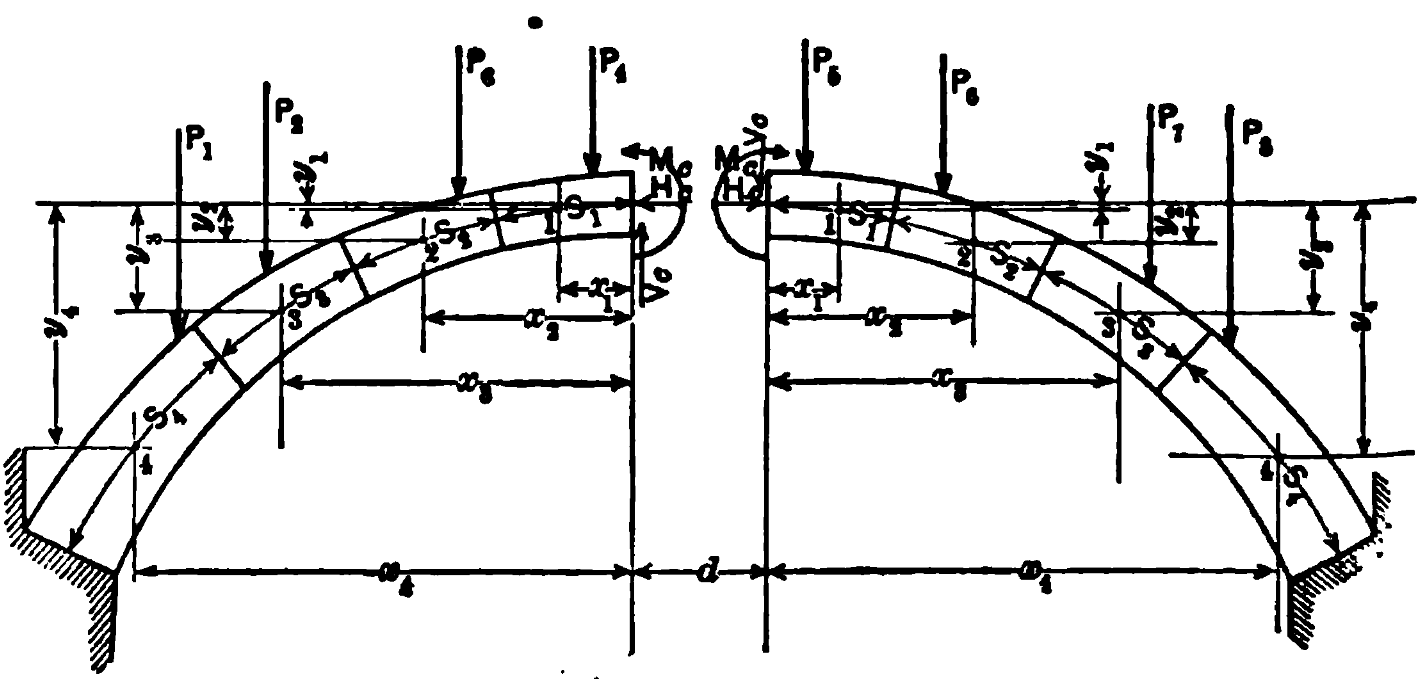


Fig. 40

the springing line as at the crown. No formula can be given to determine the tentative size of the rib in open spandrel arches. When conditions are known it is usually possible to compute the approximate thrust at the crown by moments from which a trial thickness and width can be selected.

Fill Over Crown. In solid spandrel filled highway arch bridges, the earth fill over the crown is usually equal to or somewhat greater than the thickness of the rib itself.

Locating the Line of Pressure. Fig. 40 represents any arch cut at the crown with the two halves moved apart an appreciable distance d, so that they can be considered temporarily as cantilever beams fixed at the spring-ing lines. From the following equations, the values of the thrust, moment, shear and eccentricity at the crown are determined in terms of x, y, m,

and n, summed up about the centers of the divisions 1, 2, 3, etc. as shown below.

$$H_c = \frac{n \Sigma m y - \Sigma m \Sigma y}{2[(\Sigma y)^2 - n \Sigma y^2]} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

$$M_c = -\frac{\Sigma m + 2 H_c \Sigma y}{2n} \quad . \quad . \quad . \quad . \quad . \quad (2)$$

$$V_c = \frac{\Sigma(m_R - m_L) x}{2 \Sigma x^2} \quad . \quad . \quad . \quad . \quad . \quad (3)$$

$$e_c = \frac{M_c}{H_c} \quad . \quad . \quad . \quad . \quad . \quad (4)$$

$$M = m + M_c + H y \pm V_c x \quad . \quad . \quad . \quad . \quad . \quad (5)$$

(+) sign in the last term of equation 5 is to be used on the left half of arch and (−) sign is to be used on the right half, when live load is on left hand half of arch;

in which H_c = the horizontal thrust at the crown;

M_c = the bending moment at crown, assumed positive when the stress on the upper fiber is compression and negative when the stress in upper fiber is tension;

V_c = the shear at the crown, assumed to be positive when acting upward on left half of arch as shown in Fig. 40;

M = actual moment at any section;

m = the bending moment at any point, assuming arch to be cut as in Fig. 40 and computed as tho the half were a cantilever beam, that is, m_{L2} = the moment of loads P_3 and P_4 about point 2, center of the second division on the left from crown; m is always negative;

n = the number of divisions in one half the arch determined below.

x, y = the horizontal and vertical coordinates respectively of any point on the arch axis, referred to the crown as the origin, all values for both halves being positive;

e_c = the eccentricity of the line of pressure from the arch axis at the crown, positive when above and negative when below;

I = moment of inertia of any cross-section = $I_c + r I_s$;

r = ratio E_s/E_c, usually 15;

S = length of any division of the arch ring.

In equations 1, 2, 3, 4 and 5, V_c is positive when live load is on left half only and equals zero when the live and dead loads are equal and symmetrically placed on the two halves. The quantities y, y^2, and x^2 are for one half the arch only; Σm is for the entire arch and equals $\Sigma m_R + \Sigma m_L$; $\Sigma(m_R - m_L)\, x$ is a summation in which m_R and m_L are the bending moments, as cantilever beams, at corresponding points in both halves which have equal abscissas x. $\Sigma\, m\, y$ is for the entire arch and equals $\Sigma(m_R + m_L)y$.

Equations 1, 2, and 3 require that I/S must be a constant, because I/S has been cancelled from the theoretical equations on this assumption. Each half of the arch is divided into the same number of divisions, and the centers of corresponding divisions are numbered alike from the center out. To avoid too large divisions toward the springing lines, arches of ordinary span require from seven to ten divisions in each half. The cen-

ters of these divisions are the points about which the moments m are computed and have no connection with the points at which loads are applied. For convenience only it is customary in the spandrel filled arch to assume the loads to act at the centers of the divisions. If it happens that a load comes exactly at the center over the crown, it is considered that half the dead load acts on each half, and, if loaded with live load over one half, then the whole of the live load goes to the loaded side. In showing these loads, as in Fig. 41, it is likely to save trouble if loads $K\ L$ and $L\ M$ are separated slightly at the crown.

Cost of Reinforced Concrete Arches. Ordinary spandrel filled arch bridges from 40 to 100 ft span carrying electric cars, and having 1 : 2 : 4 broken

Typical Problem. Fig. 41 represents an open spandrel highway

Fig. 41

arch bridge carrying 2000 lb live load per lin ft of bridge or 1000 lb live load per lin ft of rib. The floor design is not given. From the completed de-

sign the various loads including floor, earth fill, columns, arch rib and live load over left half only were taken as follows:

Loads on One Arch Rib

Load Designation	Dead, lb	Live, lb	Total, lb
A – B	79 000	15 000	94 000
B – C	55 000	10 000	65 000
C – D	55 000	10 000	65 000
D – E	49 000	10 000	59 000
E – F	47 000	10 000	57 000
F – G	40 000	10 000	50 000
G – H	30 000	7 500	37 500
H – I	20 000	5 000	25 000
I – J	20 000	5 000	25 000
J – K	20 000	5 000	25 000
K – L	10 000	2 500	12 500
L – M	10 000	.....	10 000
M – N	20 000	.....	20 000
N – O	20 000	.....	20 000
O – P	20 000	.....	20 000
P – Q	30 000	.....	30 000
Q – R	40 000	.....	40 000
R – S	47 000	.....	47 000
S – T	49 000	.....	49 000
T – U	55 000	.....	55 000
U – V	55 000	.....	55 000
V – W	79 000	.....	79 000
Total	.....	.....	940 000

Divide each half of the arch axis so that I/S = a constant. See Fig. 41*b*. The size of the rib, the amount of reinforcement and its position must be tentatively assumed. In this case the rib is 5 ft 6 in deep at the springing line and 3 ft deep at the crown with a constant horizontal thickness of 3 ft 6 in. Eight 1-in square rods are used in each flange thruout, 6 in from center of rods to edge of rib at the springing line and 3 in from center of rods to edge of rib at crown. Lay off the horizontal line *ad*, (see Fig. 41*b*), equal to one half the length of arch axis, that is, from springing line to crown. Select not less than four points on the arch axis at approximately equal distances apart, springing line, crown and two intermediate points, and compute, as explained below, the transformed moments of inertia of the normal cross-sections of the rib at these points. At some convenient scale erect perpendiculars at *a*, *b*, *c*, and *d*, the corresponding points in Fig. 41*b*, so that half the values of I for each point is on each side of the line *a b c d*. Then draw symmetrical curves thru the extremities of these perpendiculars. Commencing at *a*, draw an inclined line *a e*, then the perpendicular *e f*. Continue this process until the last inclined line passes thru *d*. It may require several trials to secure a suitable number of divisions. The horizontal intercepts S_1, S_2, S_3, etc, on *a b c d* now represent the lengths of the divisions of the arch such that I/S = a constant when I for any division is measured perpendicularly between the curves at the middle point of the division. Divide each half arch axis into divisions equal to S_1, S_2, etc, numbering the middle points of the divisions from the crown toward the springing line as in Fig. 41*a*.

The transferred moment of inertia is:

$$I = I_c + r\,I_s$$

in which I_c = moment of inertia of the concrete about the horizontal axis thru the center line of gravity of the cross-section.

I_s = moment of inertia of the steel about the same axis, usually taken as $A_s\,d^2$.

A_s = area of steel in arch rib.

d = distance from center line of gravity of cross-section to center of steel.

r = the ratio of the moduli of elasticity of steel and concrete = E_s/E_c = 15 by usual specifications.

The computations for the location of the line of pressure are all tabulated in Table I. The origin is taken at the crown with the X and Y axis as shown. Columns 2 and 3 give the values of the x and y coordinates of the center points of the divisions corresponding to the numbers in column 1. Columns 6 and 7 give the moments about the center points of the divisions, assuming the arch cut as in Fig. 40, and considering each half to be a cantilever beam fixed at the springing line. The results in column 8 are products of the sum of columns 6 and 7 multiplied by y for the corresponding points and all quantities are negative. Column 9 gives results for the difference between moments m_R and m_L for any point multiplied by x for the corresponding point, these results being positive when the live load is on the left half.

The quantities H_c, V_c and e_c are now computed from the Table by means of equations 1, 2, 3, and 4. The line of pressure can now be located by graphical methods as follows: Lay off the vertical loads from left to right on the line $a\,b\,c$—w, as in Fig. 41c. From 1, draw a horizontal line = H_c = 560 000 lb and at its left extremity erect a perpendicular = V_c = 13 550 lb, upward in this case because V_c is positive. z is now the correct pole position and rays are drawn from z to $a\,b\,c$—w. Scale the distance $e_c = -0.128$ ft downward from origin or arch axis at crown, and thru this point draw a line between the continuation of the load lines for loads $K\,L$ and $L\,M$, parallel to $l\,z$ in Fig. 41c. This process is continued by drawing segments of the line of pressure between the load lines parallel to the corresponding rays. The letter at the extremity of the ray always indicates the space in which the corresponding segment is drawn. H_c and V_c are plotted to the same scale as the vertical loads. The length of any ray represents the stress along the corresponding segment of the line of pressure, the last two segments of which locate the resultant arch pressure on the abutments. The remaining columns of Table I afford an accurate check on the graphical construction. Columns 10 and 11 are self-explanatory. Columns 12 and 13 are computed from equation (5) and are the true moments at the corresponding points. Columns 14 and 15 give the vertical intercepts from arch axis to line of pressure. The moment at any point as shown in columns 12 and 13 divided by H_c equals the vertical intercept at the corresponding point, and these intercepts can be immediately used to check the position of the line of pressure.

Temperature Stresses. The following formulas are used to determine the stresses due to temperature:

$$H_t = \frac{E\,I}{S} \times \frac{c\,t\,L\,n}{[2(n\,\Sigma\,y^2 - (\Sigma\,y)^2)]144} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (6)$$

$$M_{tc} = -\frac{H_t \Sigma\,y}{n} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (7)$$

Table I

	Dimensions in Feet									Moments in Foot-Pounds				
1	2	3	4	5	6					11	12	13	14 Vertical Intercepts	15
Points	x	y	x^2	y^2	m_L					$V_c x$	M_L	M_R	L	R
1	3 8	0 2	14 44	0 04	− 44 400	− 35 500	− 16 000	+ 33 800	+ 112 000	+ 51 500	+ 47 100	− 47 000	+0 084	−0 084
2	11 7	0 7	136 90	0 49	− 353 250	− 282 500	− 445 000	+ 828 000	+ 392 000	+158 500	+125 300	−121 000	+0 224	−0 217
3	19 5	1 7	380 25	2 89	− 953 100	− 762 500	− 2 920 000	+ 3 720 000	+ 952 000	+264 000	+190 900	−146 500	+0 342	−0 262
4	27 7	3 2	767 30	10 24	− 1 959 400	− 1 567 500	− 11 300 000	+ 10 850 000	+ 1 790 000	+376 000	+134 600	−225 500	+0 241	−0 402
5	37 0	5 7	1369 00	32 49	− 3 471 900	− 2 777 500	− 35 600 000	+ 25 700 000	+ 3 190 000	+502 000	+148 100	−161 500	+0 285	−0 288
6	49 3	10 0	2430 50	100 00	− 6 154 100	− 4 936 500	−110 906 000	+ 60 000 000	+ 5 600 000	+667 000	+ 41 000	− 75 500	+0 073	−0 135
7	69 4	20 5	4816 36	420.25	−12 573 275	−10 162 900	−466 000 000	+167 500 000	+11 460 000	+942 000	−253 300	+273 100	−0 453	+0 488
Σ	216 4	42 0	9914 75	566.40	−25 509 425	−20 524 900	−627 187 000	+268 631 800						
					Σ m = −46 034 325									

$$H_c = \frac{n\Sigma my - \Sigma m \Sigma y}{2\left[(\Sigma y)^2 - n\Sigma y^2\right]} = \frac{7\,[-627\,187\,000] - [-46\,034\,325 \times 42]}{2\,[\overline{42}^2 - 7 \times 566.4]} = 560\,000 \text{ lb}$$

$$M_c = -\frac{\Sigma m + 2H_c\Sigma y}{2n} = -\frac{-46\,034\,325 + 2 \times 560\,000 \times 42}{14} = -72\,000 \text{ ft-lb}$$

$$V_c = \frac{\Sigma (m_R - m_L)\,x}{2\Sigma x^2} = \frac{268\,631\,800}{2(9914.75)} = +13\,550 \text{ lb}$$

$$e_c = \frac{M_c}{H_c} = \frac{-72\,000}{560\,000} = -0.128 \text{ ft}$$

$$e_t = \frac{M_{tc}}{H_t} = -\frac{\Sigma y}{n} \quad \ldots\ldots\ldots\ldots\ldots \quad (8)$$

$$M_t = M_{tc} + H_t y \quad \ldots\ldots\ldots\ldots\ldots \quad (9)$$

in which H_t = thrust at crown due to temperature, positive for rise and negative for a fall in temperature;

M_{tc} = moment at crown due to temperature and always opposite in sign to H_t, in foot-pounds;

M_t = moment at any point due to temperature;

e_t = eccentricity of temperature thrust measured down from the origin in feet (a horizontal line drawn below arch axis at crown by an amount e_t cuts the arch axis at two points where moments due to temperature are 0, and this line locates the true position of the temperature thrust);

c = coefficient of expansion, usually taken as 0.000 006 per degree F;

L = span of arch axis measured between springing lines;

t = change in temperature in degrees F, either plus or minus.

In equations (6) to (9) inclusive, E, I, L, and s are in inches, H_t in pounds, M_t in foot-pounds, e_t in feet, y in feet, and $[2(n\Sigma y^2 - (\Sigma y)^2)]$ is in feet. The latter expression is taken from Table I, and is the same as in the denominator for value of H_c except the signs are changed to give a positive value to H_t for a rise in temperature.

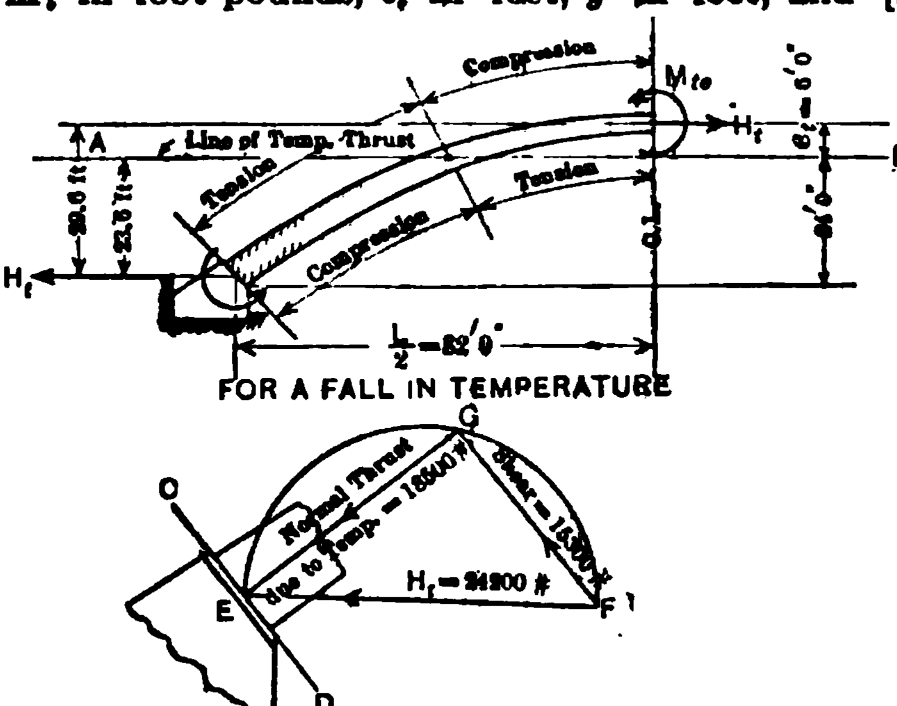


Fig. 42

Fig. 42 represents the conditions for a fall in temperature, moments and thrusts having opposite signs from those shown for a rise in temperature.

In the illustrative problem, I/S = 2300, E = 2 000 000, c = 0.000 006, L = 164 ft = 1968 in, n = 7, $t = \pm 40°$ F., $2(n\Sigma y^2 - (\Sigma y)^2)$ = 4392 sq ft. And for a rise in temperature.

$$H_t = \frac{2\,000\,000 \times 2300\ (0.000\,006 \times 40° \times 1968 \text{ in} \times 7)}{4392 \times 144} = 24\,200 \text{ lb}$$

$$M_{tc} = -\frac{24\,200 \text{ lb} \times 42}{7} = -145\,200 \text{ ft lb}$$

$$e_t = -\frac{42}{7} = -(6 \text{ ft}) \text{ at springing line from equation (8).}$$

Moment due to a rise in temperature, M_{ts} = − 145 200 ft lb + 24 200 × 29.6 ft = + 570 000 ft lb, or more directly M_{ts} = 24 200 lb × 23.6 ft = + 570 000.

The normal thrust on any cross-section due to temperature can be deter-

mined by the method of Fig. 42, in which H_t is resolved into two components, normal and parallel respectively to the cross-section. The temperature thrust is taken as the diameter of a semicircle $E F$. Then any line drawn from the extremity of the diameter as $E G$ parallel to a normal on any cross-section, to its intersection with the circle, measures the normal thrust at the section, which, in the case shown, is at the springing line. The line $G F$, always at right angles to $E G$, measures the shear on the section due to temperature. The normal thrust at any section due to vertical loading is obtained from Fig. 41c by resolving that ray, that cuts the section in question, into two components at right angles such that one is normal to the section.

Stresses in the Arch Ring. The stresses in the arch ring are obtained by combining the effects of thrust and moment at the given section. When temperature stresses are considered, it is convenient to combine the moments due to vertical loads and to temperature and to similarly combine the thrusts, using the resulting values for moment and thrust in the equations. If the line of pressure is everywhere within the middle half, middle third for plain concrete, the usual formulas for combined stress are accurate enough. These are as follows:

$$f_c = \frac{N}{A_c + r A_s} \pm \frac{N e u}{I_c + r I_s} \qquad (10)$$

$$f_s = \frac{r N}{A_c + r A_s} \pm \frac{r N e v}{I_c + r I_s} \qquad (11)$$

in which f_c = unit stress in extreme fiber of concrete;
f_s = unit stress in extreme fiber of steel;
N = normal thrust on cross-section;
u = distance from center line of gravity of cross-section to extreme fiber of concrete;
v = distance from center line of gravity of cross-section to extreme fiber of steel;
r = ratio E_s/E_c and usually = 15;
The denominators of equations (10) and (11) are respectively the transformed areas and moments of inertia of the cross-sections, the latter of which can be scaled directly from Fig. 41b;
Ne = the moment at the section, equals normal thrust times eccentricity, but when temperature moments have been combined it is more convenient to substitute directly the total moment for Ne.

The formulas involve the assumption that every fiber in the cross-section carries its proportion of the stress. When therefore, a solution shows a tensile stress in concrete of about 150 lb per sq in, about the ultimate strength of concrete, the formulas begin to be unreliable. If the line of pressure is very eccentric or the temperature thrust is very large, it may be found that these formulas do not apply and others suitable for such condition may need to be used. Such equations are, however, difficult to solve without proper curves and cannot be given here. The equations and accompanying curves are given by Taylor and Thompson (20). The usual equations are satisfactory for the illustrative example, but it will be found that they reach this limit of usefulness in the solution for stresses at the springing line.

Stresses at crown of arch. See Fig. 41a.

Thrust due to vertical loads	$= +$	560 000 lb
Thrust due to rise in temperature of 22° C (40° F)	$= +$	24 000 lb
Total thrust at crown		584 200 lb
Moment due to vertical loads	$= -$	72 000 ft lb
Moment due to rise in temperature of 22° C (40° F)	$= -$	145 200 ft lb
Total moment at crown	$= -$	217 200 ft lb
	$= -$	2 606 400 in lb

Transformed area at crown $= A_c + r\,A_s = 1736$ sq in
Transformed I at crown $= I_c + r\,I_s = 213\,400$ sq in
$u = 19.5$ in $\qquad v = 16$ in.

Maximum compressive stress in lower fiber of concrete from equation (10):

$$f_c = \frac{584\,200 \text{ lb}}{1736 \text{ sq in}} + \frac{2\,606\,400 \text{ in lb} \times 19.5 \text{ in}}{213\,400 \text{ in}^4}$$
$$= 336 \text{ lb per sq in} + 239 \text{ lb per sq in}$$
$$= 575 \text{ lb per sq in compression in concrete.}$$

Minimum compression stress, f_c, on upper fiber at crown:

$$f_c = 336 \text{ lb per sq in} - 239 \text{ lb per sq in}$$
$$= 97 \text{ lb per sq in compression in concrete.}$$

Maximum compression stress in steel at crown in lower fiber from equation (11):

$$f_s = \frac{584\,200 \text{ lb} \times 15}{1736 \text{ sq in}} + \frac{15(2\,606\,400 \text{ in-lb} \times 16 \text{ in})}{213\,400 \text{ in}^4}$$
$$= 5040 \text{ lb per sq in} + 2940 \text{ lb per sq in}$$
$$= 7980 \text{ lb per sq in in compression in steel.}$$

Minimum compressive stress in steel at crown in upper fiber:

$$f_s = 5040 \text{ lb per sq in} - 2940 \text{ lb per sq in}$$
$$= 2100 \text{ lb per sq in compression in steel.}$$

Stress at springing line of arch (see Fig. 41*a*). On account of greater eccentricity, the right side is selected.

Thrust due to vertical loads	$= +$	712 000 lb
Thrust due to rise in temperature of 22° C (40° F)	$= +$	18 500 lb
Total thrust at springing line	$= +$	730 500 lb
Moment due to vertical loads	$= +$	670 000 ft lb
Moment due to rise in temperature of 22° C (40° F)	$= +$	570 000 ft lb
Total moment at springing line	$= +$	1 240 000 ft lb
	$= +$	14 880 000 in lb
Transformed area $= A_c + r\,A_s$ at springing line	$=$	2996 sq in
Transformed $I = I_c + r\,I_s$ at springing line	$=$	1 170 000 in^4

$u = 33$ in $\qquad v = 27.5$ in.

Maximum compression stress in concrete at springing line in upper fiber from equation (10):

$$f_c = \frac{730\,500 \text{ lb}}{2996 \text{ sq in}} + \frac{14\,880\,000 \text{ in lb} \times 33 \text{ in}}{1\,170\,000 \text{ in}^4}$$
$$= 244 \text{ lb per sq in} + 420 \text{ lb per sq in}$$
$$= 664 \text{ lb per sq in compression in concrete.}$$

Maximum tensile stress in concrete at springing line in lower fiber,

$$f_c = 244 \text{ lb per sq in} - 420 \text{ lb per sq in}$$
$$= 176 \text{ lb per sq in in tension.}$$

Maximum compression stress in steel at springing line in upper fiber from equation (11):

$$f_r = \frac{15(730\ 500 \text{ lb})}{2996 \text{ sq in}} + \frac{15(14\ 880\ 000 \text{ in lb} \times 27.5 \text{ in})}{1\ 170\ 000 \text{ in}^4}$$

$$= 3660 \text{ lb per sq in} + 5240 \text{ lb per sq in}$$

$$= 8900 \text{ lb per sq in compression in steel.}$$

Maximum tensile stress in steel at springing line in lower fiber:

$$f_s = 3660 \text{ lb per sq in} - 5420 \text{ lb per sq in}$$

$$= 1580 \text{ lb per sq in tension in steel.}$$

Without considering temperature, the maximum compression stress in concrete at the springing line is found to be 465 lb per sq in and no tension exists. These stresses are satisfactory for the sections selected. If the unit stress should prove to be too large or too small, the shape of the arch rib would need to be revised and new computations made.

11. Stone Masonry Arch Highway Bridges

The masonry arch has been largely superseded by the reinforced concrete arch. Only brief mention will here be made of some of the characteristics of such arches, and it should be noted that no attempt has been made to give any principles of design. For complete discussions, reference should be had to works on masonry and arches, see (2), (12a) and (16b).

Parts of an Arch. Baker (2) gives the following definitions: ABUTMENT, a skewback and the masonry which supports it. BACKING the masonry outside and above the arch stones, which usually has joints horizontal or nearly so. CROWN the highest part of the arch. EXTRADOS, the convex curve which bounds the outer extremities of the joints between the voussoirs. HAUNCH, the indefinite part of the arch between the crown and the skewback. INTRADOS, the concave line of intersection of a vertical plane with the lower surface of the arch. KEYSTONE, the center or highest voussoir or arch stone. RISE, the vertical distance between the highest part of the intrados and the plane of the springing lines. SKEWBACK, the inclined surface or joint upon which the end of the arch rests. SPAN, the horizontal distance perpendicularly between the lowest joints of the arch. SPRINGING LINE, the inner edge of the skewback. SPANDREL, the indefinite space between the extrados and the roadway. The wall at the end of the arch above the extrados is called the spandrel wall; and the material between the end walls and above the extrados is called the spandrel filling. VOUSSOIR, one of the wedge-shaped stones of which the arch is composed; also called an arch stone. The voussoirs which show at the ends of the arch are called RING STONES; and those which do not thus show are called ARCH SHEETING. If the intrados is a semicircle, the arch is a FULL CENTERED ARCH, and if less than a semicircle, it is a SEGMENTAL ARCH.

Methods of Failure. An arch may fail: (1) By crushing; (2) by sliding of one voussoir on another, or by sliding upon the foundation; (3) by rotation about some joint. Settlement of the foundation is a common primary cause of failure. Baker (2) states that to prevent (1) " the line of resistance should intersect each joint far enough from the edge so that the maximum pressure will be less than the crushing strength of the masonry "; to prevent (2) " the angle between the line of resistance and the normal to any joint should be less than the angle of repose, angle of friction, for those surfaces; that is to say, the tangent of the angle between the line of resistance

and the normal to any joint should be less than the coefficient of friction"; to prevent (3) "it is necessary that the line of resistance shall everywhere lie between the intrados and the extrados." For good design, the line of resistance should be inside the middle third of the arch ring.

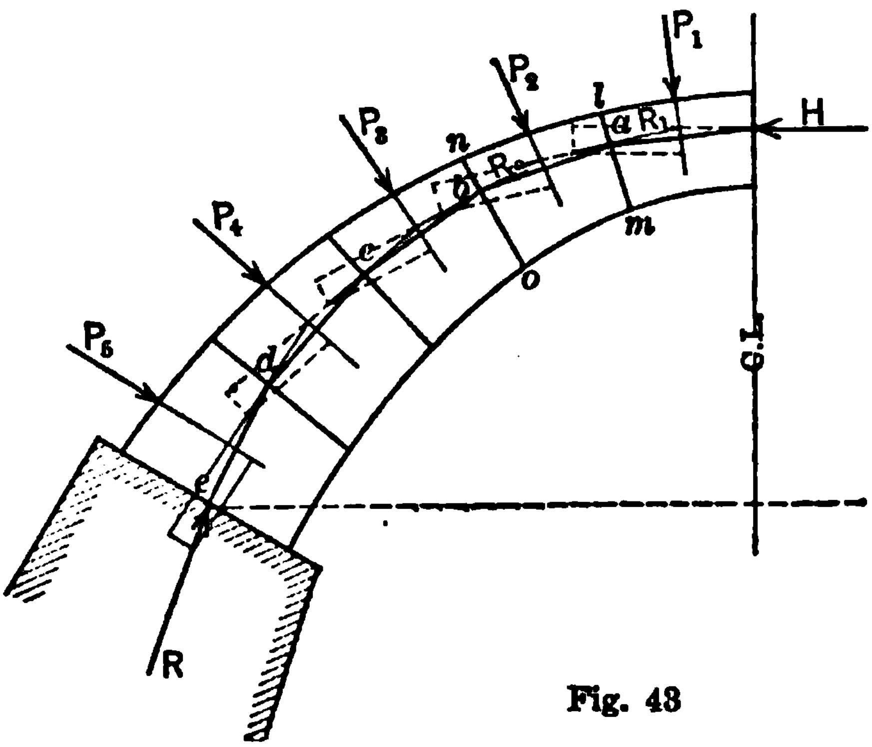


Fig. 43

Line of Resistance. Fig. 43 shows the forces acting upon ½ of a masonry arch. This arch has been divided into imaginary sections by lines as shown. Assuming that the arch is symmetrically loaded and that all forces are known in magnitude, direction and line of application, H and P_1 may be combined giving R_1 which intersects l m at a. R_1 is combined with P_2 giving R_2 which intersects n o at b, etc. The points a, b, c, d, e are called centers of resistance and the polygon developed by connecting them is called the line of resistance, which approaches a curve as the number of divisions of the arch is increased.

CULVERTS

12. Location and Design of Culverts

Culverts are usually placed on the line of natural water courses, at the bottom of the sag in the profile of the original ground. Nearly always, they are placed under fills, and occasionally under cuts. They should cross under the highway as nearly as possible at right angles to its center line. This saves in cost.

The Size of a Culvert depends upon the rate of rainfall per hour for a period of time equal to the time required for water to reach the culvert from the farthest part of the drainage area. That is, if all the rain falling on an area reaches a culvert in 10 min, and a maximum rainfall of ½ in in 10 min is recorded, then the rate of rainfall for that culvert would be 3 in per hr. For large areas, the maximum rainfall in 1 hr is used. The size depends on the size of the drainage area, and also upon its shape and configuration; thus a nearly square or circular area requires a larger culvert than one which is long and narrow, one with well defined valleys requires a larger culvert than one consisting of a flat slope. The size depends also upon the amount of vegetation and cultivation; trees and brush by retarding the flow of water and cultivation by making the soil more absorbent may decrease the size of culvert necessary. In warm climates, size depends upon porosity of soil. On extremely sandy soils 30 to 50% of rainfall will reach the culvert; on heavy clays, 90 to 100%. Long heavy rains will saturate any soil until nearly the entire rainfall will run-off to the culvert. Frozen ground will give 100% run-off, to which should be added allowance for rain melting snow.

Formulas. Probably the two formulas which have been used more than any others for size of culverts are as follows: In Atlantic states, Myer's

formula $A = C \sqrt{\text{ACRES IN DRAINAGE AREA}}$; in Mississippi valley states, Talbot's formula; $A = C \sqrt[4]{(\text{ACRES IN DRAINAGE AREA})^3}$. In both formulas, A is the cross-section of the culvert in square feet; C varies, in Myer's formula, from 1 for rolling country and 1.5 for hilly ground to 4 for mountainous or rocky ground; and in Talbot's, from $\frac{1}{6}$ for long, narrow valleys to 1 for steep, rocky ground. The following method is recommended for determining the size of culvert: $V = C\sqrt{s}$, where V = velocity of water in miles per hour, C varies between 10 where contours are straight and 40 where there is a well defined valley, and s is the ratio of slope. If by this formula V is greater than 7, use $V = 7$. $T = D/V$, where T is the time in hours required for water to reach the culvert from the most remote part of the area, and D is the distance from that point to the culvert in miles. $Q = \frac{1}{2} r \sqrt[4]{S A^3}$, where Q is the discharge in cubic feet per second, r is the rate of rainfall in inches per hour for time T, S is slope in percent, A is acres in area. The cross-section of the culvert equals $Q/10$.

13. Construction of Culverts

For Pipe Culverts under low fills, use two or three pipes side by side in place of one larger pipe. Use pipe culverts up to capacity of two 24-in pipes. Be sure that conditions at the lower end of the culvert will carry off water as fast as the culvert discharges. Lay all pipe culverts nearly level from upper end for half its length, then slope at least one in ten to lower end, rounding off change of slope. Settlement of fill is thus taken care of. The bottom of the inside of the pipe at each end should be at the elevation of the natural soil. All pipe culverts have at least 1 ft of fill over them, and where traffic causes very heavy loads, 2 ft. If the fill is not over 10 ft, double strength, vitrified sewer pipe may be used. This comes in lengths of 24 in, 30 in or 36 in dependent on the size of the pipe. If the soil is firm, excavate about 1 ft wider than the size of the pipe and about 8 in below the pipe grade. Fill in with gravel, bedding the pipe thereon, but use care that the pipe bears entirely upon its barrel and not on its bell ends. Lay the pipe to the true line and grade beginning at the lower end of the culvert and facing the bell ends towards the upper end of the culvert. Caulk joints with oakum and fill in the remainder of the joint with a mixture of one part Portland cement and one part sand. In backfilling, fill slowly in thin layers and tamp thoroly on both sides of the pipe. As pressure on top of the pipe tends to burst out the sides, do not tamp hard directly over it.

Cast Iron Pipes are always better than vitrified pipe culverts and the extra cost is more than compensated for by their greater permanency. They are constructed similarly except that the joints of the cast iron pipes are filled with lead, instead of cement mortar, which gives a much more pliable joint.

Orrock's "Railroad Structures and Estimates" (18) gives the following weights for cast iron pipe, and cost at $35 per ton:

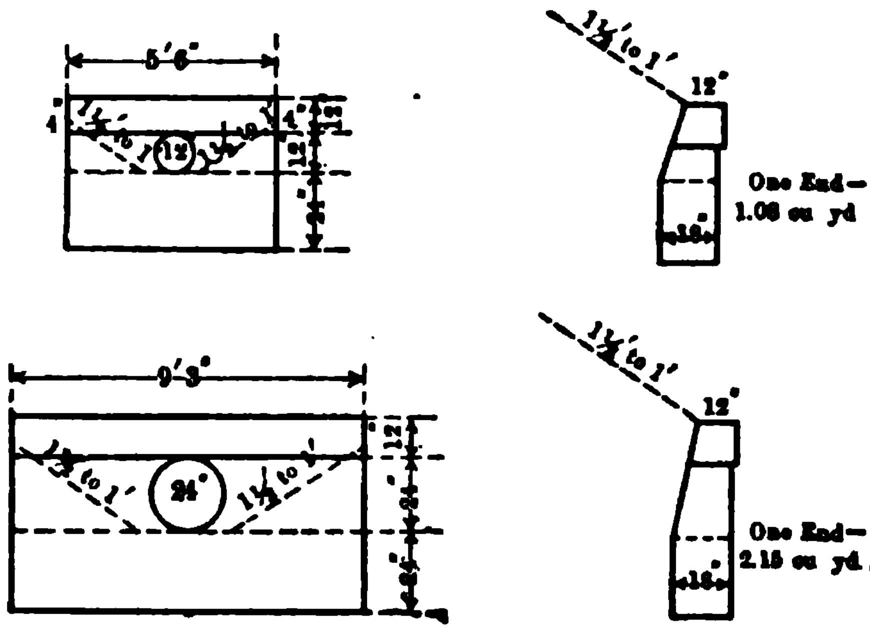
Diameter	Weight per Ft	Cost per Ft
8 in	53 lb	$0.93
10 in	73 lb	1.28
12 in	95 lb	1.66
14 in	119 lb	2.09
16 in	147 lb	2.57
18 in	176 lb	3.08

Corrugated Metal culverts have come rapidly into use in highway construction, as corrugation gives a very high strength in proportion to the

weight of the material. Corrugated metal culverts come from the factory in sections of semi-circumference 2 ft in length, taking two sections to form a complete pipe. It is made in sizes of from 8 in to 72 in in diameter. Trenching is done as for other pipe culverts except that there are no bell ends to be cared for. Owing to its light weight, the culvert may be put in place with less trouble than with any other pipe. Backfilling should be done with just as great care as is used for other pipes.

Corrugated metal culverts are also made in one piece complete circular sections in lengths up to 36 ft. These lengths are fastened together by corrugated metal collars covering adjoining ends and bolted. All corrugated metal culverts should be galvanized; the coating should contain not less than ¾ oz of zinc per sq ft of each side of the metal. The approximate cost per lin ft is about as follows: 8-in, 54 cents; 12-in, 72 cents; 18-in, $1.04; 24-in, $1.44; 36-in, $2.84; 48-in, $4.14.

Concrete Pipe. Altho both plain and reinforced concrete culvert pipe is on the market, the reinforced pipe is much better, because of its lighter weight for a given strength. This pipe is made in a variety of sizes, the smaller sizes being reinforced with wire mesh and the larger with hoops and longitudinal bars. Care must be used in laying as the hoop reinforcement is near the inside of the pipe at the top and bottom and near the outside at the sides of the pipe. These pipes are cast in 2½ and 3-ft lengths and have bell and spigot joints, which are filled with cement mortar, one part Portland cement and one part sand.



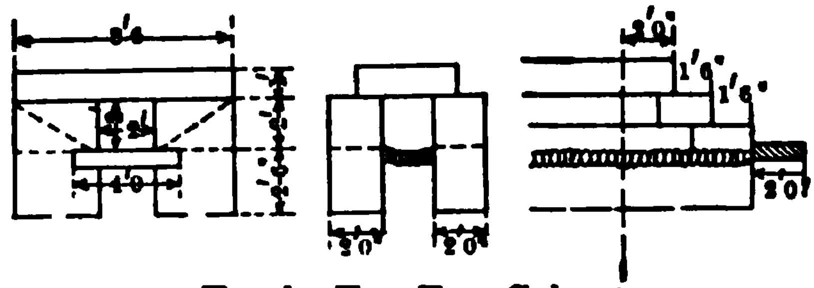
Notes: 8-in Pipe Culvert, one end, 4 ft 2 in long; 0.77 cu yd.
10-in Pipe Culvert, one end, 4 ft 10 in long; 0.92 cu yd.
16-in Pipe Culvert, one end, 6 ft 10 in long; 1.42 cu yd.

Fig. 44

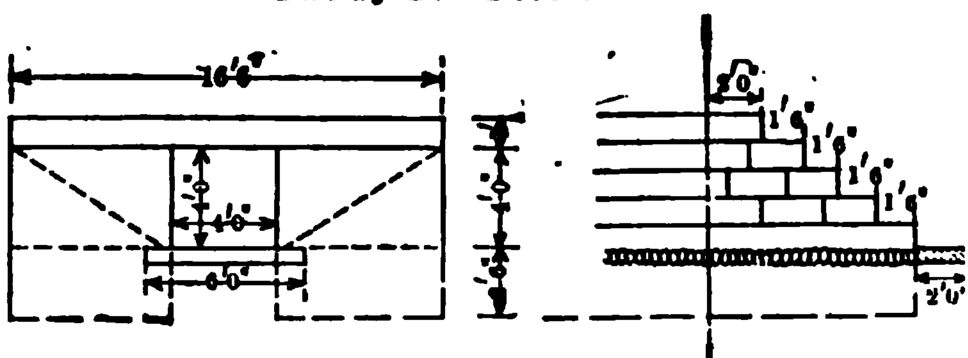
End Walls for Pipe Culverts. Massachusetts standard concrete end walls for pipe culverts are shown in Fig. 44. It is estimated that end walls cost about $8 per cu yd of concrete in place.

Stone Box Culverts may be used where large blocks of stone are available and where the use of concrete materials would require a long haul. The cover stones must be large enough to overlap for at least 1 ft on each side wall. This type of culvert may be built double in order to increase its capacity, the center wall being built with a cut-water end. The side and center walls, which should have a thickness of not less than 0.4 their height, are built of large stone laid in Portland cement mortar and extend at least 2½ to 3 ft below the natural surface of the ground, with spread footings if necessary, to secure a proper bearing. The floor of the culvert is paved with cobblestones set on end, so that their tops are in the same general plane, and grouted with Portland cement mortar. Massachusetts standards for stone box culverts with end walls and also with stepped ends are shown in Fig. 45.

Reinforced Concrete Culverts. For spans of 4 to 10 ft thru small fills, use plain concrete sides and reinforce the top and bottom by embedding old railroad rails in 10 to 12 in of concrete. Place rails 12 in centers, except under heavy traffic, in which case the rails in top of culvert should be 8 or 10 in centers, the top to bear at least 1 ft on each side wall. The side walls should be 2 ft thick at the top and should batter on the earth side to a thickness at the bottom of not less than 0.4 their height. If soil is firm, make the floor of paving stone as for a stone box culvert. If soil is not firm, make the floor similar to the top, but place rails both transversely and longitudinally. This is not strictly reinforced concrete, as the load is carried entirely by the rails, the concrete merely protecting the rails and making them act together.



Two by Two Foot Culvert

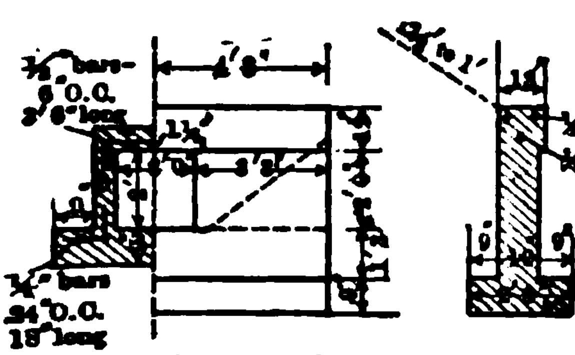


Four by Four Foot Culvert

Notes: 2 by 2 ft Culvert, one end: Above foundation, 1.59 cu yd; foundation, 1.20 cu yd; apron, 4 by 2 by 0.5 ft, 0.15 cu yd; walls, covers, paving, 0.864 cu yd; paving, 8 in deep.
2 by 2 ft Culvert, end stepped, one end: Above foundation, 1.7 cu yd; foundation, 2.10 cu yd; apron, 4 by 2 by 0.5 ft, 0.15 cu yd; walls, covers, paving, 0.864 cu yd.
4 by 4 ft Culvert, one end: Above foundation, 4.92 cu yd; foundation, 2.31 cu yd; apron, 6 by 2 by 0.5 ft, 0.22 cu yd; walls, paving, 1.11 cu yd; covers, 0.22 cu yd; paving, 12 in deep.
4 by 4 ft Culvert, end stepped, one end: Above foundation, 4.0 cu yd; foundation, 4.15 cu yd; apron, 6 by 2 by 0.5 ft, 0.22 cu yd; walls, paving, 1.11 cu yd; covers 0.22 cu yd.

Fig. 45

Baker (2) gives the following FORMULAS for the design of regular reinforced concrete box culverts: For top and bottom: $M = S^2 (100\,H + L)$; for side walls, $M = 1.4\ (2H\,h^2 + h^3)$; where M = maximum bending moment in inch-pounds, S = clear span in feet, H = height of embankment above inside of culvert top in feet, L = live load in pounds per square foot, h = clear height of culvert in feet. Considering 1 ft of length of either top, bottom or side as the beam, the thickness may be found from: $d^2 = M/f_s\,p\,j$ or $d^2 = M/f_c\,kj$. Ordinary values of $k = 3/8$, $j = 7/8$ and $p = 0.008$ to 0.015. Working values of f_s = 12 000 to 15 000 and of f_c = 400 to 650. As reinforcement should be bedded 2 in in concrete, thickness = $(d + 2)$ in. Area of steel reinforcement per foot of length = $M/f_s\,j\,d$.

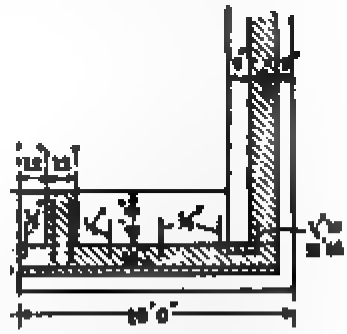


Notes: Reinforced Concrete 2 by 2 ft Culvert. Data per foot of culvert section: Concrete, 0.2346 cu yd; steel, ¼-in bars, 0.318 lb and ½-in bars, 5.95 lb.
Data for one end: Concrete, 1.72 cu yd; steel bars, one ½-in bar, 8 ft long, two ¼-in bars, 8 ft long, two ¼-in bars, 2 ft long; weights, ½-in bars, 6.8 lb and ¼-in bars, 4.24 lb.

Fig. 46. Two by Two Foot Reinforced Concrete Culvert

Massachusetts standard reinforced concrete box culverts are shown in Figs. 46 and 47.

Reinforced concrete culverts, as well as all other kinds vary exceedingly in cost according to location and conditions of construction. A culvert in one place may cost twice or three times what its exact duplicate may have cost elsewhere, but a fair average for estimating the cost of reinforced concrete culverts is about $14 per cu yd of concrete. Inasmuch as reinforced



Notes: Reinforced Concrete 6 by 6 ft Culvert. Data per foot of culvert section: Concrete 0.727 cu. yd; steel, $\frac{1}{2}$-in bars, 21.248 lb and $\frac{1}{4}$-in bars, 3.824 lb.

Data for one end: Concrete, 3.02 cu yd, steel bars, six $\frac{1}{2}$-in bars, 9 ft long, two $\frac{1}{2}$-in bars, 8 ft 5 in long, one $\frac{1}{2}$-in bar, 7 ft long, four $\frac{1}{2}$-in bars, 11 ft long, four $\frac{1}{4}$-in bars, 8 ft 5 in long, two $\frac{1}{4}$-in bars, 7 ft long, fourteen $\frac{1}{4}$-in bars, 2 ft long; weights $\frac{1}{2}$-in bars, 103.553 lb and $\frac{1}{4}$-in bars, 16.041 lb. All sizes calculated for deformed square bars of medium steel.

Fig. 47. Six by Six Foot Reinforced Concrete Culvert

concrete box culverts are now built with a clear space as great as 20 ft, there is little advantage in using arch culverts, as they require more head room and the expense of forms is much greater than for concrete box.

Timber Box Culverts. In country where timber is very plentiful and it is difficult to bring in pipe or materials for concrete, timber box culverts may be used. They should be built large enough to build pipe culvert inside before the expiration of the life of the timber. Double 4 by 4 ft box is the largest capacity that it is economy to build. Side walls should be built of 12 by 12 in timber, laid lengthwise of culvert, and drift bolted together. The cover should be of 8 by 12 in timber, laid with 8-in vertical, placed across the culvert, with a 12 by 12 in every 4 or 5 ft let in so that the lower 4 in may act as a strut between the side walls. The bottom should be of 3 by 12 in plank laid longitudinally thru the culvert on 2 by 12 in battens placed at intervals of about 5 ft.

RETAINING WALLS

14. Design of Retaining Walls

Efforts to obtain formulas for the design of retaining walls have been made by generations of engineers, but owing to almost innumerable combinations of conditions met with, it is practically impossible to give theoretical formulas for their design. All theories are based on the assumption that the surface or rupture of retained earth is a plane. It is a well-known fact that ordinary soils may be dug out to a vertical plane and will stand in that condition for a short time due to cohesion of the particles composing

it. First failure will leave the surface concave upwards. Weather will change this surface near the top to convex upwards. The surface of rupture, therefore, is not a plane. Theories are also based on the assumption that the point of application of resultant pressure is at one-third of the height of the wall above the bottom. In wet soils the point of application will be not much higher than this owing to large water pressure; but with drier soils, the point will be higher, dependent upon the quality of retained material, and may be as high as the middle of the wall. Ordinarily this point is about 0.4 of the height above the bottom. The most used theory. Rankine's, assumes the direction of pressure as parallel to the surface of retained earth. As this would make a given wall more stable when retaining earth with surcharge than with earth with level top, it is, of course, untenable. All experiments show that the direction of pressure is not horizontal. Experiments have proved that there is a very material amount of friction between the earth and the back of the wall. This does not appear in any theoretical formulas, but certainly increases the stability of a wall. In general, then, the cohesion of the particles making up the retained earth, and the adhesion of these particles to the back of the wall make theoretical formulas of little value for ordinary retaining walls used in highway work. If a wall is built to retain a highway in fill, the material comprising the fill, and the method of placing it may be such as to decrease the load against the wall. Such fills should be made in layers, sloping away from the wall thus decreasing both earth and water pressures. Also pressure is decreased by providing proper drainage for water. If the retained roadway is higher than the top of the wall, the extra height is known as SURCHARGE, and the wall must be heavier in such a location. Heavy highway traffic should be figured as so much surcharge, and consider soil to weigh 100 lb per cu ft. Retaining walls used where the highway is in cut will often be heavily surcharged, as sloping ground may rise for a considerable distance above the wall. Such cases require walls of maximum thickness.

Retaining walls may fail (1) by SLIDING OR SHEARING along a plane that is horizontal or nearly so; (2) by OVERTURNING about the front edge of the base; or (3) by CRUSHING at the front edge of the base or other horizontal joint. It is generally conceded that a well-built stone masonry wall that will not fail by overturning, is strong enough not to fail by sliding either on its base or any horizontal joint. As most retaining walls are now built of concrete, and are keyed to the foundation, the resistance to sliding is materially increased and is amply sufficient even with light reinforced concrete walls.

In order not to overturn or crush, the THICKNESS OF THE WALL at the base should be about 35 to 40% of its height, and the slope or step back of the wall to a thickness of 2 ft at the top of the main wall. For ordinary surcharge make the thickness at base 50% of height. The coping at the top should not be considered as part of the retaining wall. The face of wall may be vertical, altho a batter of ¾ or 1 in to the ft gives a better appearance. Walls built of first-class material and of above thickness should not crush. Most failures of retaining walls are due to poor foundations and not to failure of the wall itself. As most soils are at least slightly compressible, unless sufficient spread is given to footing courses, the extra pressure at the front edge of the base may cause undue settlement and a tilting of the wall. If great enough, this unequal settlement may cause actual failure in a wall which otherwise would be perfectly safe. Therefore if the soil is at all questionable, pile foundations should be used. Under

the above conditions small walls are built to lean slightly toward the earth, thus throwing the center of pressure on the base back of the center.

The most COMMON SECTION for a retaining wall is as given above, namely, nearly vertical face and sloping or stepped back. Also, as noted above, considerable saving in material may be made by sloping both face and back of wall back towards the retained earth. In this latter section, care should be used to keep the vertical thru the center of gravity within the base. This section is not advised for high walls because of the heavy action of frost. Stability of these sections is dependent entirely upon the weight of the masonry. With reinforced concrete, the weight of part of the retained earth makes up for decrease in masonry.

Good drainage is very important. Wet soil is much heavier than dry. Wet clay has but little cohesion and the wall has to resist the thrust of a much greater mass of earth. The force of water freezing back of the wall is liable to cause serious trouble. To drain off the water, build a 3-in pipe thru the wall near the bottom at intervals of from 10 to 20 ft. If the earth back of the wall is sand or gravel, water will reach these outlets easily, otherwise a vertical layer 15 to 20 in thick composed of broken stone or clean gravel should be placed back of the wall.

15. Reinforced Concrete Walls

Nearly all such walls for highway work are of the CANTILEVER TYPE, having a base of concrete somewhat wider than half the height of the wall and from 1 to 2 ft thick. From near the middle of this base rises the wall, leaving nearly half of the base covered with the retained earth, the weight of which helps to resist overturning. For high walls, over 20 or 25 ft, or where foundation and wall must not cross the property line, a COUNTERFORTED WALL may be used. This differs from the cantilever in that the wall rises from one edge of the base, the remainder being loaded with retained earth. Also, counterforts, vertical walls at right angles to face of wall, are placed about every 8 ft which are of the same thickness as the main wall at the base but taper to nothing at the top.

To Design Reinforced Concrete Retaining Walls, first assume the section for a plain concrete retaining wall according to the rules given above. Assume that this plain concrete wall is a dam, retaining a fluid of such weight as to cause the resultant pressure to pass thru the front end of the middle third of the base. Taking 1 ft of length of this plain concrete wall, the moment of its weight is its weight times the distance from the front end of the middle third of the base, taken as the center of moments, to the point where the vertical thru the center of gravity cuts the base. This resisting moment $= 1/6\, w\, h^3$, where h is height of wall and w is weight of fluid as above stated. Solve this for w. Now assume that the reinforced concrete wall, together with the retained earth vertically above the back end of the concrete base, is a dam, retaining fluid having a weight of w lb per cu ft. Design for 1 ft of length of wall. Assume weight of concrete as 150 lb per cu ft and the weight of earth above back part of base as 100 lb per cu ft. Find center of gravity of these and draw a vertical line thru the center of gravity. Thru a point $1/3\, h$ above the base draw a horizontal line. From intersection of these lines lay off to some scale on the vertical line the weight of concrete and earth as given above, and on the horizontal line the value of $\frac{1}{2}\, w\, h^2$. If the resultant of these forces cuts the bottom of the base within its middle third the wall will be safe from overturning or crushing. As reinforced concrete walls are thin, the matter of horizontal shear is

important. The force tending to shear is $\frac{1}{2}\, w\, h^2$ for each foot of length. Assuming concrete to have a safe resistance to shearing of 25 lb per sq in, the least thickness at the bottom of a vertical wall to safely resist shear is $w\, h^2/600$ in per ft of wall. Even reinforced concrete walls are usually much thicker than this.

16. Construction of Retaining Walls

Stone Masonry retaining walls should be built of stones free from imperfections and durable in courses not less than 12 in thick. To secure proper transverse bond, every fourth stone should be a header and at least as wide as thick. The headers should extend entirely thru the wall unless it is more than 4 ft thick. The stretchers should be at least $1\frac{1}{2}$ times as wide as thick, and at least 4 ft long. The beds and vertical joints should be about $\frac{1}{2}$ in thick, dressed and squared at least 10 in back from the face of wall, care being taken that a vertical joint in one course does not come within 8 in of the vertical joint in the course next below and spalls should be used where needed. Backing of wall should consist of large stones, well bedded on horizontal beds without spalls. The wall should be completely covered by a coping composed of large stones not less than 8 in thick, unless the wall is over 4 ft thick. This coping must not overlap the plane of the back of the wall, as frost will lift it.

Plain Concrete. Moorefield (55) gives the following data for plain concrete retaining walls, see Fig. 48: $W = H/12$, never less than 10 in; $b = 4/10H$, never less than 10 in; for $H < 6$ ft, B need never be greater than $4/10\ H + 1$; for $H > 6$ ft, $B = 4/10\ H + 0.75$ rock foundation, $B = 4/10\ H + 1$ good gravel foundation, $B = 4/10\ H + 1.25$ medium gravel foundation, $B = 4/10\ H + 1.5$ good clay foundation, $B = 4/10\ H + 1.75$ medium clay foundation.

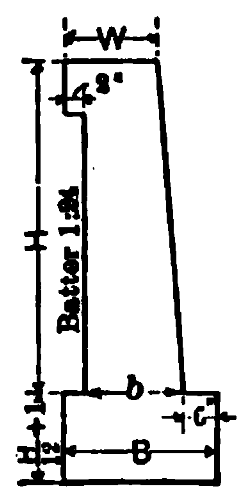


Fig. 48

Forms for plain concrete walls should be made of green lumber which will not swell from contact with wet concrete. The boards should be 1 in thick, tongued and grooved. For the back of the wall, it is not necessary to plane either side but the face of the boards against face of wall must be planed, and better results are obtained if the faces in contact with the concrete are also planed as the forms will come off cleaner. The lumber must be free from all loose knots, the best being used for the face of the wall. Straight parallel edges are necessary to make tight joints. Studding, 2 in by 4 in for low walls and 2 in by 6 in for higher walls, should be spaced 2 ft center to center. Forms for the backs of walls are ordinarily braced from the ground, for even small failure in braces will have bad results, if only on the appearance of the walls. Forms for faces of walls should be braced as follows: Fasten small 2-in wooden blocks inside each form, one opposite the other, having $\frac{5}{8}$-in holes thru forms and blocks; from block to block have piece of $\frac{1}{2}$-in pipe to separate forms; thru the holes in the forms and thru the pipe pass $\frac{3}{8}$-in iron rods, threaded at each end, and long enough to pass thru the entire form and have nuts screwed up outside of forms at both ends. When forms are removed, remove rods and fill up holes in wall formed by the 2-in wooden blocks with rich mortar. Before placing forms in position, coat their faces with soft soap to permit of forms being removed earlier, thus allowing the concrete to set more rapidly. This also permits surfacing face of wall while concrete is still green. Heavy oil or other grease may be used in place of soft soap; but latter is

not injurious to cement and is easily soluble in water when form is cleaned. Before placing concrete in forms, clear out all sawdust, pieces of wood, etc. Use 1:3:6 concrete for base of wall, 1:2½:5 concrete for main wall, and 1:2:4 concrete for coping. The Portland cement must meet the ordinary commercial tests, the sand must be coarse and clean, and the gravel or broken stone clean, that is free from dust and organic matter. The pieces making up the gravel or broken stone should be of hard and durable materials and of spherical or cubical shape, not long and thin, the stone for plain concrete being not greater than 3 in in any dimension. In large masses of concrete, however, large stones, called PLUMS, may be inserted to decrease the amount of concrete necessary. Such stones should be rammed into the concrete in order to bring them into intimate contact with the concrete on all sides and must not be within 2 in of any form or of each other. Their total volume should not exceed 30% of the volume of the wall. Mix cement and sand dry until color is uniform, then add stone and water and mix until each stone is thoroly coated with mortar.

Contraction. Concrete contracts when setting due largely to drying out of water. To prevent a wall from cracking in an unsightly manner, provide vertical contraction joints every 25 to 40 ft by building wall to full height in sections of this length and fastening on the inside of the end of the form a 2 by 4 in vertical scantling so that, when form is removed, there will be a vertical groove in end of section. In casting the next section, this groove will be filled with a concrete tongue. The bond between the new concrete and the old will be so poor that contraction will break it, but the tongue and groove will maintain the strength of the wall. Unless concrete is put in place rather dry and in cold weather, there is little probability of its ever having a tendency to increase in volume. Such an expansion would call into play the compressive strength of the concrete, which in practically all cases would be sufficient to withstand the stresses without danger of buckling.

Reinforced Concrete Walls. Moorefield (55) gives the following data for reinforced concrete retaining walls.

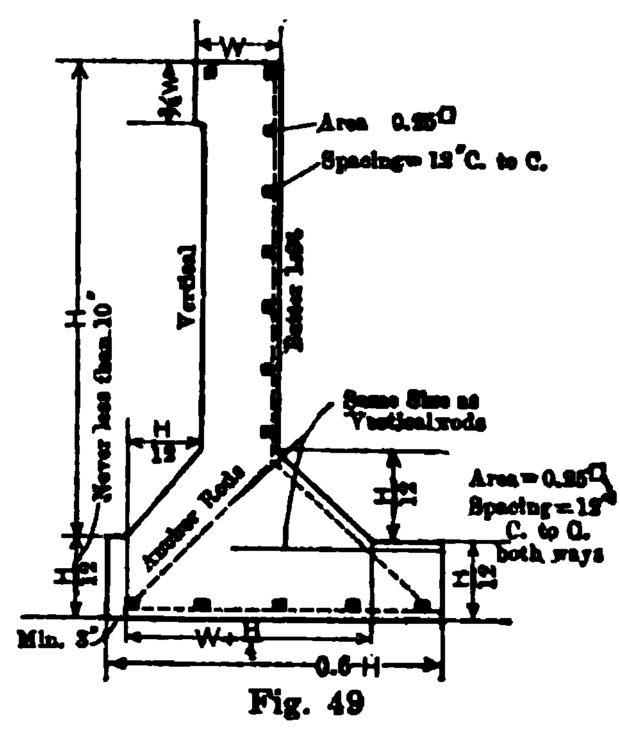


Fig. 49

H	W	Vertical Bars Size	Vertical Bars Spacing
2 ft	0 ft 7 in	½ by ½ in	12 in *c* to *c*
4 ft	0 ft 7 in	½ by ½ in	12 in *c* to *c*
6 ft	0 ft 7 in	½ by ½ in	12 in *c* to *c*
8 ft	0 ft 8 in	½ by ½ in	10 in *c* to *c*
10 ft	0 ft 9 in	½ by ½ in	8 in *c* to *c*
12 ft	0 ft 10 in	⅝ by ⅝ in	8 in *c* to *c*
14 ft	1 ft 0 in	⅝ by ⅝ in	6 in *c* to *c*[1]
16 ft	1 ft 0 in	¾ by ¾ in	6 in *c* to *c*[1]
18 ft	1 ft 2 in	¾ by ¾ in	5 in *c* to *c*[2]
20 ft	1 ft 4 in	¾ by ¾ in	4 in *c* to *c*[3]

[1] Alternate bars end 8 ft up from base.
[2] Alternate bars end 9 ft up from base.
[3] One-third of bars end at 4 ft and one-half at 10 ft up from base. The note (3) regarding spacing in 20-ft wall would probably better read one-third of bars end at 7 ft and one-half of the remainder at 14 ft up from base.

Forms. Even greater care is necessary in the building of forms for reinforced concrete than for plain concrete on account of the thin masses of

concrete. All reinforced concrete should be a 1:2:4 mixture, the stone used being not greater than 1 in in any dimension. Reinforcement should be firmly held in place by fine strong wire connecting various rods to each other and to the forms. At joints of longitudinal reinforcement, lap rods at least 25 times the least dimension of the rod and bind thoroly with strong ductile wire. In placing concrete use great care not to displace the reinforcement, and to have the concrete come into intimate contact with the reinforcement on all sides.

FOUNDATIONS

17. Bearing Power of Soils

Wherever the abutments or piers of a bridge are to be placed, and in a lesser degree, wherever a retaining wall is to be placed, the soil should be thoroly examined as to its ability to sustain the load. The soil at the site of a retaining wall may be examined by driving sections of gas-pipe by hand from a scaffold. Great changes of conditions of the soil are obtainable in this manner. For bridge foundations, it is better to obtain samples of the soil at various depths by means of a post-hole auger. But these samples are not entirely satisfactory as they do not give the condition of compression of the soil in place. For important bridges, probably the best way to determine the bearing power of the soil is to excavate a well to a considerable depth, if possible to the bottom of the estimated footings, and load a vertical timber 12 in square.

Bed Rock will undoubtedly carry any load which may be placed upon it under these conditions. But if the surface of the rock slopes to any considerable degree, great care must be used to bond the masonry to it in such a way that it cannot possibly slide. The lowest portions of concrete should be rich in cement.

Gravel. Thick beds of clean, dry gravel will safely carry loads of from 6 to 10 tons per sq ft.

Sand and Clay may give good bearing power if perfectly dry, or nearly so in the case of sand. But under ordinary conditions, it is difficult to prevent the entrance of water into such soils, and then the bearing power decreases very materially. If clay is on top of rock, a little moisture makes it impossible for foundation work, whereas the mixture of a small amount of clay in good sand or gravel will increase its bearing power.

Table II.—Safe Bearing Power of Soils by Baker (2)

Kind of Material	Safe Bearing Power in Tons per Square Foot	
	Minimum	Maximum
Rock, the hardest in thick layers in native bed	200	..
Rock, equal to best ashlar masonry	25	30
Rock, equal to best brick masonry	15	20
Rock, equal to poor brick masonry	5	10
Clay in thick beds always dry	6	8
Clay in thick beds moderately dry	4	6
Clay soft	1	2
Gravel and coarse sand well cemented	8	10
Sand, dry, compact and well cemented	4	6
Sand, clean, dry	2	4
Quicksand, alluvial soils, etc	0.5	1

18. Foundation Footings

The load to be carried by the foundation may be obtained by finding the weight of the entire structure to be supported and adding to that the extra pressure due to retained earth in retaining walls and bridge abutments; and the live loads and impact due to heavy traffic over bridge abutments and piers. This latter effect is very small and often negligible. Having found the load to be supported, the area of support is found by dividing this load by the safe bearing power of the soil. In order to obtain area enough at the bottom of the masonry to decrease the load on the soil to a safe value, and also to make the resultant pressure on the soil pass as nearly as possible thru the middle of the base, it is necessary to spread the footings. The amount of this spread is dependent upon the ability of the masonry to withstand the upward pressure of the soil. Having found the width of masonry in contact with the soil necessary to make the pressure fairly uniform thruout that width, and also to make the maximum unit pressure a safe one, the next step is to determine the decrease in width possible for the course of masonry on top of the bottom course, and so on up until the main part of the abutment or pier is reached. This offset as used for masonry footing courses is given in the following Table III by Baker (2), which gives a factor of safety of 10.

Table III.—Safe Offset for Masonry Footing Courses

Kind of Masonry	Offset in Terms of the Thickness of the Course for a Pressure in Tons per Square Foot on the Bottom of the Course of		
	0.5	1.0	2.0
North River bluestone	5.2	3.7	2.6
Granite	3.1	2.2	1.6
Limestone	2.7	1.9	1.4
Sandstone	2.7	1.9	1.4
Under burned building brick in 1 : 3 Portland, cement mortar at 76 days	1.9	1.4	0.9
Vitrified building brick in 1 : 3 Portland cement mortar at 76 days	4.9	3.1	2.2
1 : 2 : 4 Portland cement concrete at 1 month	1.2	0.9	0.6

Soils. Nearly all natural soils are compressible. Some not materially so, others considerably so; usually due to the presence of a comparatively small amount of water. In some cases greater bearing power may be obtained by simply going deeper. The weight of the soil causes it to be more compact at a greater depth. Another simple and very effective way of increasing the bearing power is by efficient drainage. Drain tile, placed a little lower than the bottom of a footing course, will materially increase the bearing power. But such drainage must have a proper outlet. If springs are encountered in making excavation, they should be led away by proper drainage. Efforts to plug them are liable to cause serious damage as they are often backed by a high head of water. Where soil contains considerable moisture, clean sand or gravel may be spread over the bottom of the excavation in layers of from 6 to 12 in and rammed into the soil. Small wood

piles may be driven into the soil. These are about 6 ft long and 6 to 8 in in diameter. Such piles are in no sense bearing piles, but merely compact the soil and act with it in forming a bed for the foundation. Additional bearing power may be obtained by withdrawing these wooden piles and filling the holes with dry sand, ramming the sand into place. This ramming increases the size of holes and further compacts the soil.

19. Pile Foundations

Where the soil is very wet and cannot be compressed so as to give sufficient bearing power, piles are commonly used. The most common piles are of wood. These should be fairly straight thruout their length and be not less than 7-in diameter at the tip. In hard driving, hard woods are best. In easy driving, soft woods are nearly as good. Woods that split readily do not make good piles for drop-hammer driving. There are two different kinds of pile-drivers. The drop-hammer driver has an iron hammer weighing from 1500 to 2000 lb falling freely between two vertical timber leaders 40 or 45 ft high. The hammer is raised by a rope which passes over a block at the top of a leader and winds up on a drum at the ground level. This driver gives heavy blows at comparatively long intervals. The steam hammer has a hammer weighing 2500 to 3000 lb driven thru a short blow by steam piston. The entire weight of the frame holding the steam cylinder and hammer rests on top of the pile and is guided by a leader as in a drop-hammer driver. The steam hammer gives very rapid blows, not allowing the earth to come to rest about the pile. It is a well authenticated fact that in most soils, the pile has greater bearing power some time after being driven than it has immediately after the last blow of hammer. The steam hammer takes advantage of the reverse of this condition.

In soils composed of silt, clay, fine sand or other fine materials, the sinking or driving of piles may be greatly assisted by use of a JET OF WATER applied at the tip of pile. This is carried by a hose or pipe down the side of a pile to the tip. It makes no apparent difference if the discharge is not under the center of the tip. The action is not to force the material out of place, but to flood the soil under pile so that the weight of the pile with the hammer on top will cause the pile to sink into it. Therefore, a large amount of water is required rather than high nozzle velocity.

In some cases, the upper portion of the soil may have no supporting power whatever, so that even if a pile penetrates hard pan, the upper part of the pile will act as a column fixed at the bottom. But in all ordinary cases, its resistance to buckling is greater than its bearing power under such conditions. Bearing power is dependent upon the bearing power of soil under the tip, usually small, plus friction between the sides of pile and the surrounding soil. Most commonly used formulas for bearing power are Engineering News Formulas, devised by Wellington: For drop-hammer driver, safe load in pounds $2\,wh/(s+1)$. For steam hammer driver, safe load in pounds $2\,wh/(s+0.1)$. In both formulas, w represents weight of hammer in pounds, h the fall of hammer in feet for last blow, and s the penetration of pile in inches under that blow. This last blow should be struck on solid wood and not on a broomed-out end. For large structures, or where the soil is very irregular, piles may be loaded to determine the bearing power. This is the only practical way to find the bearing power of concrete piles. Knowing the load to be carried, and the safe bearing power of pile, the number of piles may be determined by simple division. It is common to space piles on 3-ft centers in staggered rows.

Concrete Piles. Except for temporary structures, wood piles should not be used except where they will always be wet, unless they are thoroly creosoted. Recent years has seen the introduction to a large extent of concrete piles. These not only withstand ordinary decay, but are also unaffected by the various wood destroying animals in southern waters. The Raymond concrete pile is made by driving into place a tapering shell of sheet iron covering a collapsible core. These may be had of almost any ordinary size. After driving, the core is collapsed and withdrawn. The shell is filled with concrete. The Standard Simplex pile is made by first driving a cast iron cylinder, to the bottom end of which is loosely fastened a blunt pointed cast iron cone. After driving, concrete is placed to a depth of 2 or 3 ft and the cylinder is raised leaving the point in place. The concrete is in contact with soil, and by tamping, further compression of the soil is obtained. This process is repeated until the top of the pile is reached. Both Raymond and Simplex piles may be reinforced. The use of iron and steel piles has been almost entirely discontinued by the introduction of concrete piles.

Sheet Piling is used for coffer-dams where it is necessary to work several feet below the normal water level. Wood sheet piling is made by driving 2 by 6 to 10 in planks edge to edge. These should be carefully guided in order to keep the joints tight. Waling-pieces are used to help guide the piling. Also the tip to one edge of plank is sharpened. Two or three thicknesses of planks will give the best results, each thickness breaking joints with those already driven.

Steel Sheet Piling will withstand much greater pressures. They are driven in just the same way as the plank, except that they interlock on their edges, and thus assure practically tight joints. Joints may be made tight by driving wooden strips into the interlock. These swell and tighten the joints. While steel piling has a higher initial cost, it may easily be withdrawn and used again, whereas the plank is largely destroyed.

If bed rock can be reached without serious difficulties, footing courses for bridge abutments and piers should be placed on such rock. This does away for all time with any trouble from scour during spring floods. Even with sand and gravel, the footings should be carried well down below the top surface unless piles are used. And in all cases, other than rock bed, large stone or rip-rap should be piled around the bottom of the abutment or pier in sufficient quantity to avoid all danger due to scour.

See (2), (9) and (12b).

20. Coffer-Dams

The most common method of placing footings and foundations under water is to build some form of coffer-dam around the site and pump out the water. If the water is not over 3 or 4 ft deep, and there is practically no current, the coffer-dam may be built of material excavated from the site of foundation. If there is a current, washing away of such a wall may be prevented by surrounding it with bags filled with gravel or with gravel and clay. If the current is very considerable, build the entire wall of bags filled with gravel and clay. For depths up to 6 or 8 ft, plank sheet piling may be used without a puddle. A puddle-wall coffer-dam is built by driving two rows of sheet piling all around the site of foundation. The distance between the two rows should not be less than ¼ the depth below the water level. This space is always filled with gravel, gravel and clay, or gravel and loam. Gravel should always be present, as leaks thru the

puddle will often stop themselves by gravel filling the leak. Clay or loam will arch over such a leak and not fill it. For depths up to about 10 ft, the rows of sheet piling may be braced by 8 by 8 in timbers forming a horizontal frame all about the inside of the piling. These timbers are called wales. For greater depths, it may be necessary to drive ordinary wood piles from 6 to 10 ft apart and brace the sheet piling to these. See (9) and (12b).

21. Pumps

The use of coffer-dams involves the use of some kind of pump to keep the site of the foundation free from water. If the water is shallow and the dam is tight, the water may be removed by an ordinary plunger pump worked by hand. Such a pump is, however, seldom sufficient. The diaphragm pump consists of a short cast iron cylinder with a flexible rubber diaphragm horizontally across at the mid-height of the cylinder. The pump handle, fastened to the middle of the diaphragm, gives the piston action by the rise and fall of the diaphragm, in center of which is the valve. It is operated by hand or by gasoline engine and has a capacity of 25 to 100 gal per min.

Steam Siphon Pumps operate by the creation of a partial vacuum in the intake pipe by the injection of steam within or near the entrance to the discharge pipe. Of the several siphon pumps on the market, the most common is the pulsometer. If water in large quantities must be handled, the centrifugal pump should be used. This is a siphon pump where the vacuum is created by a fan revolving in a cylindrical case. The intake is at the center of the cylinder and the discharge is at the circumference. The amount of water handled is dependent upon the speed of the fan which may be run at from 400 to 700 rev per min. The most common sizes have discharge pipes of 6, 8 and 10 in and the largest at high speed having a capacity of 14 000 gal per min. See (9) and (12b). Another important advantage of a centrifugal pump is that the only valve is the flap valve at the foot of the intake. When in use, this is constantly open and permits the free passage thruout the pump of stones of considerable size.

GUARD RAILS

22. Wooden Guard Rails

Along both sides of fills of any considerable depth, there should be built guard rails or fences. Wooden fences are built of cedar, white oak or chestnut posts 6 in in diameter. These are 6 ft 6 in, Massachusetts standard, or 7 ft, Connecticut standard, in length, placed 3 ft 6 in above the ground. The top of the post is fish-tailed in the line of the fence and the top rail is made of 4 by 4 in timber set into fish-tail so that the diagonals of cross-section of timber are horizontal and vertical. Or the top of post may be sloped about 30°, and 2 by 6-in planks spiked across the tops. Posts are set 8 ft apart, and rails should be 16 ft in length. Another rail of 2 by 6-in plank should be fastened to highway side of the posts so that the top edge of this rail is about 1 ft 6 in below the top of the post. All joints in the top rail should be covered with a sheet of zinc thoroly nailed down to prevent water from getting into the joint. The entire fence should be painted with two coats of white lead and oil, making them visible at night. Such guard rails cost from 25 to 40 cents per lin ft.

23. Iron Pipe Railing

Across culverts or where the road is retained by masonry walls, pipe fences may be used. The Massachusetts standard iron pipe fence requires the posts to be of 2-in pipe and rails to be of 1½-in pipe. There are 3 rails spaced 13 in center to center, the center of bottom rail being 16 in above the ground. The Connecticut standard requires posts to be of 3-in pipe and rails to be of 2-in pipe. Two rails 15 in center to center, the center of bottom rail being 15 in above ground. Posts are set not more than 8 ft center to center and are sunk 10 to 12 in into the masonry thru cast iron flanges, which are 6 in in diameter for 2-in pipe and 7 in in diameter for 3-in pipe. The flanges are bolted to the concrete by four ⅝-in or ¾-in bolts. The fences should be painted with two coats of white lead paint.

24. Cement-Concrete Guard Rails

Concrete. Wherever there is slightest danger from brush fires, or where timber is more expensive than concrete materials, concrete and wire fences or concrete fences may be built. Concrete posts should be about 7 ft long with 3 ft 6 in in the ground. They are 5 in square at top end and 6 in square at bottom end. For wire fences, place ½-in round rods, greased, in the forms in which the posts are cast, in such a way that the rods may be withdrawn leaving holes for the wire strands to pass thru. Or take pieces of No. 12 copper wire, bend in the middle and insert them in the post forms so that about 2 in of the free ends will be outside the face of the posts to fasten the wire fencing to the posts. Cost will vary from 10 to 25 cents per lin ft.

Concrete guard rails may be built of concrete rails set on top of concrete posts. The rails are built with a rectangular trough section fitted with cross diaphragms connecting the side and top. The rails are generally reinforced and are set about 3 ft 2 in above the ground. The cost of concrete guard rails is estimated to be about 50 cents per lin ft.

Concrete Parapet Walls in place of pipe rail fences may be built 2 ft 6 in high and 8 in thick with panels 1 ft 2 in high and not over 7 ft 4 in in length for 8 ft center to center of panels, sunk 1 in deep into each side of the wall, making the wall 6 in thick at panels, and leaving 8 in of thickness around the panels. This wall should be reinforced by 3-in 10-gauge expanded metal weighing 0.9 lb per sq ft, placed in the middle of the thickness of the wall running its entire length, and extending from the bottom of the wall to within 3 in of the top. Also in the middle of the thickness of the wall and wired to expanded metal, should be placed ¾-in twisted square rods extending vertically from 3 in below top of wall to 20 in into concrete below parapet wall. These should be spaced not over 4 ft center to center, that is, two to every panel length; 1½ to 2 in inside the two top corners of the wall should be placed ⅜-in twisted square rods running horizontally the entire length of wall. At each end of wall and cast as an integral part of the wall, place concrete post 12 in square and 2 ft 8 in high, having the corners chamferred to match the panelling of the wall. The top of post should be a square pyramid, 1 in high. Place one of the ¾-in vertical rods in the middle of the post and continue the expanded metal thru 10 in of the post, that is, within 2 in of the end of concrete.

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SECTION 27

PRESERVATION OF MATERIALS USED IN HIGHWAY STRUCTURES

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CORROSION AND PRESERVATION OF IRON AND STEEL

DECAY AND PRESERVATION OF WOOD AND MASONRY

CORROSION AND PRESERVATION OF IRON AND STEEL

1. Corrosion of Metal

Causes of Corrosion. Iron corrosion is generally due to self-electrolysis which is distinct from the type of external corrosion caused by escaped currents from high potential electric lighting or power circuits. Iron always contains impurities such as carbon and manganese which, when segregated, in the presence of moisture, are electrically opposed to iron. These impurities are generally of an electro-negative nature and thus force the electro-positive iron into solution. The air present oxidizes the iron in solution and precipitates it out as rust. The water thus freed from the iron oxide again attacks the metal, serving as an electrolyte for the currents that flow from different areas of the surface. Under favorable circumstances, this reaction may proceed until the metal is entirely transformed into rust. This would indicate that the approach of iron or steel to chemical purity will lead to added resistance to corrosion. The presence of impurities invites segregation which causes surface differences of potential and stimulates electrolytic action. Freedom from gases is also an important factor in the manufacture of corrosion-resisting metal. Scratches, pitholes or abrasions on steel become centers of corrosion, as they are electro-positive to surrounding areas. In assembling metal parts in structural work, metals containing different percentages of carbon or other impurities are apt to set up corrosion at points where they touch, the electro-positive metal being rapidly destroyed. It is therefore advisable to have all rivets of the same composition as the plates which they fasten together.

Acids present in water stimulate electrolytic action. Contact with carbonaceous substances also stimulates corrosion, as such substances tend to make iron more electro-positive, and thus increases the differences of potential. Unequal strains or stresses on the surface of the metal also have a corrosive tendency.

Effect of Water and Impurities in Water. The presence of carbonic and sulphuric acid in the air in industrial communities causes considerable more corrosion at such points. These impurities are absorbed from the air by rain water which may fall upon iron structures. Waters containing most salts or acids increase the electrical conductivity of the solution and therefore stimulate the galvanic action which is responsible for corrosion. Salt water stimulates corrosion rapidly on account of its conductivity. Mine waters stimulate corrosion on account of the presence of sulphuric acid. Strongly alkaline water actually inhibits corrosion, as it tends to make the surface of the metal passive to electrolysis. Very dilute alkaline water, however, causes a tendency to pit. The presence of dissolved oxygen in water causes rapid corrosion. If water, which is to be used for boiler purposes, is first freed from its oxygen content, much less corrosion of the tubes will occur. The oxygen in sewage-laden waters has been used up in oxidizing the organic matters present. For this reason, sewage water does not exert as corrosive an action upon metal as ordinary fresh water. Iron assumes a passive state, in which it will not rust, after it has been dipped into a strong solution of certain oxidizing agents, such as chromic acid, potassium bichromate or strong nitric acid. This passivity of surface remains for some time, even after removal from the oxidizing reagents. Bichromate of potash is probably the most efficient inhibitor. Two pounds of the salt dissolved in 3000 gal of water furnishes a solution which will keep steel bright when immersed therein. The surface of the steel is rendered passive and does not rust. Immersion of steel in a 5% solution of potassium bichromate, subsequently washing off the solution, produces a passivity which resists corrosion in the air for some time. In rapidly moving waters highly charged with oxygen, the corrosion of iron would not be as great as in still waters similarly charged. This is especially true of pipe lines. It is due to the fact that the constant swirl of the waters prevents differences of potential on various surfaces from being permanently established, as would be the case if the water was quiet.

2. Preservation of Metal

Zinc Coatings. Zinc is a highly electro-positive metal and is best suited to use as a metal protective coating on iron. On account of its electro-positive nature, it goes into solution in water, the iron being electro-negative in this reaction and thus protected from corrosion. There are three methods of applying zinc coatings to iron. The HOT DIP METHOD is carried out by dipping or drawing the iron thru a tank of melted spelter, subsequently drawing thru asbestos wipers or putting thru rolls to remove the excess zinc. The iron is first pickled in acid to remove the scale from the surface. The presence of any considerable percentage of arsenic in the zinc produces an inferior coating. Alloys of zinc and iron, when formed in the bath and coated upon metal, reduce the electro-positive nature of the coating and thus reduce its efficiency. In the ELECTROLYTIC METHOD OF GALVANIZING, the zinc is deposited in a pure condition by electrolysis of a zinc solution. The method, however, requires consid-

erable time and consumes much current. Heavy smooth coatings cannot always be obtained. The VAPOR PROCESS of depositing zinc is known as SHERARDIZING. The articles to be coated, generally small articles, such as hardware, are placed in an iron drum, in contact with zinc dust, and a temperature of 316° C (600° F) reached. In one process the articles are placed in a rotating cage in contact with the gas from a reservoir of molten zinc. In vapor processes very even coatings are obtained, the inner part of which is generally alloyed with the iron. Articles vapor-galvanized have a surface which takes paint much better than the smooth spangled surface produced by hot galvanizing.

Tin Plate. Tin is extremely resistant to corrosion and is therefore used in a large way for coating iron to form tin plate, especially for roofing purposes. It is difficult to apply a coating of tin to a metal so that pinholes are not left; in fact, most all tin plate contains pinholes at various spots, the uncoated iron upon exposure going into solution and forming rust spots. These are easily detected on new tin by floating over the surface of the plate a solution of hot gelatine containing a small amount of potassium ferri-cyanide. The gelatine hardens upon cooling. The pinholes will be shown by a brilliant color which indicates reaction between the uncoated iron and the potassium ferri-cyanide, with the formation of Prussian blue. Heavily coated tin plate will show very few, if any, spots.

Copper is used to a considerable extent for the coating of metal; copper-coated wire and copper-clad steel being especially valuable for some purposes. In case of abrasion, however, rapid corrosion is apt to occur, since iron is strongly electro-positive to copper. This corrosion, however, proceeds for a time and then stops, a thin film of copper compounds forming as a preservative coating over the iron.

Lead is used to a considerable extent for coating iron (terne plate), and for some purposes is very useful. It is not as durable as well galvanized or heavily coated tin plate.

Special Protective Treatments. There are many other methods of treating iron, among which may be mentioned the BOWER-BARFF PROCESS of producing a surface of black magnetic oxide by heating the metal to 815° C (1500° F) in a chamber to which is admitted superheated steam or producer gas rich in carbon monoxide, black magnetic oxide being thus formed upon the surface. This is quite extensively used for small articles, such as iron grilling, builders' hardware, stove pipes, etc. The cost of the treatment ranges from $5 to $20 a ton. Articles, thus coated, are resistant to corrosion, but when they are scratched or abraded rapid corrosion will occur, since the coating is electro-negative. Many articles made of iron which cannot be subjected to the various treatments previously mentioned are sometimes made of alloys containing chromium, vanadium and other metals. These are resistant to corrosion but are expensive. Immersion of iron in fused sodium nitrate and other salts gives surface oxide coatings which are more or less resistant for a time to corrosive tendencies but are less effective than the protection given by paint.

3. Paints for Iron and Steel

Paint for Metal. In the design of protective coatings for metal surfaces, the modern practice has been to apply the results of recent studies into the causes of corrosion. Since in these studies it was found that substances of a basic nature or materials which contain soluble chromates prevent the

corrosion of iron, pigments of a basic nature or pigments which contain the chromate radical have been widely adopted for use in paints for the protection of metal from corrosion. In exposure tests at Atlantic City to determine the durability of various pigments in oil as protectives of metal surfaces, over 300 large steel test panels were exposed in 1908. See Proc. Am. Soc. Test. Mat., 1910–1917. These were all given three coats of paint made of various materials. Careful inspections were made every year, the rating of 10 indicating perfect protection and 0 indicating total failure. The ten panels receiving the highest ratings during 3 years of inspection are given herewith:

Ten Highest Ratings

1912		1913		1914	
Pigment	Rating	Pigment	Rating	Pigment	Rating
American vermilion	9.9	American vermilion	9.8	American vermilion	7.5
Zinc-and-lead chromate	9.2	Zinc-and-lead chromate	8.3	Sublimed blue lead	6.0
Sublimed blue lead	9.0	Zinc chromate	8.0	Carbon black	5.0
Zinc chromate	8.8	Willow charcoal	7.9	Chrome green	5.0
Willow charcoal	8.6	Zinc-and-barium chromate	7.8	Willow charcoal	4.5
Chrome green	8.6	Magnetic black oxide	7.8	Red lead	4.0
Magnetic black oxide	8.6	Chrome green	7.6	Natural graphite	4.0
Zinc-and-barium chromate	8.5	Sublimed blue lead	7.2	Zinc chromate	4.0
Sublimed white lead	8.1	Carbon black	6.8	Zinc-and-lead chromate	4.0
Red lead	8.1	Prussian blue (water stimulative)	6.7	Magnetic black oxide	4.0

Unfortunately, chromate pigments are expensive and are therefore used only in small percentages in metallic paints, generally in combination with iron oxides. The sublimed lead pigments, the iron oxide pigments and red lead are reasonable in price and have therefore been adopted as the bases of many protective coatings.

Inspection of Metal Surfaces. In inspecting painted metal to determine the durability of various paints, the following should be noted. Chalking of paint is shown when the paint is rubbed with the hand or a black cloth. This indicates destruction of the oil. Moderate chalking is not detrimental. Checking or crazing of surface is shown by paints which are not elastic and which become brittle upon exposure. Elasticity of film can be determined by scraping the paint with a knife. Brittle coatings crumble; elastic paints produce long elastic films. The underlying metal should be examined with a magnifying glass for evidences of rust. Hardness of paint and resistance to moisture are shown by drawing a line with a fountain pen upon the surface. If the ink does not spread, the surface is hard and does not absorb moisture.

Painting Galvanized Iron. Galvanized iron is widely used for siding, roofing, railings, cornice work, drain pipes, fence wire, etc. On account of the smooth, spangled surface, ordinary paints will peel after a short period of time. This may be overcome by first treating the metal before painting with a solution made by dissolving 4 oz of copper acetate, copper sulphate or copper chloride in 1 gal of water. The application of this solution produces a rough dark surface. A few hours after the applica-

tion, the surface may be lightly brushed and then painted with a rust inhibitive paint. The paint will firmly adhere to such a surface.

Painting Tinned Surfaces. The rapid corrosion of tin plate points to the necessity of painting tin roofs a day or so after placement. The palm oil or other grease upon the surface may be removed by wiping with a cloth saturated with benzine. The paint may then be applied. Iron oxide paints containing 10% of zinc chromate have given excellent results for this purpose.

Painted Culverts. Culverts, plain or corrugated, are usually galvanized. If the coating is heavy, the corrosion resistance is usually excellent except in strongly alkaline soil that has a solvent effect upon zinc. Black iron culverts that have been painted may replace galvanized culverts for some purposes. The black culvert segments should be coated at the factory with a rust inhibitive priming coat of paint made of red lead, blue lead, chromated or litharged iron oxide, etc. After forming, the culverts should be dipped at the fabricating shop in a black, water-resisting, liquid bituminous paint made of asphalt or blown petroleum residue. Such paints dry rapidly and do not become soft during shipment as would be the case if the culverts were dipped in hot asphalt or tar. Culverts treated in the manner outlined above should withstand corrosion for many years, if the base metal is corrosion resistant.

Bituminous Paints. Tar and asphaltic paints have come into wide use for coatings upon cast iron or riveted steel water carriers. Some of these are made by blending asphalt with coal tar pitch, linseed oil, resinous varnishes and similar ingredients, altho the modern practice is to use heavy petroleum residue, sometimes fluxed with gilsonite. This is usually heated to 150° C (302° F) or over in order to bring it to a molten condition, the heated pipes being plunged therein and removed. The adhered coating becomes hard in the air in a short period of time. Subsequent baking produces a more resistant film.

Coal tar paints for brushing purposes should be made from refined tar that has been freed from ammonia and water, which cause saponification and non-adherence. The presence of much naphthalene or free carbon is detrimental to such paints and is apt to cause crazing and early disintegration. For the preparation of coal tar paint, refined tar should be heated to 120° C (248° F) until the water is evaporated. Ten percent of quicklime may then be added to neutralize the free acids. A small quantity of Portland cement may also be added, if desired. This mixture may be applied hot. When making a thinner paint to be applied with a brush, there may be added to the heated coal tar 5% of quicklime, 5% of red lead and 20% percent of gloss oil made by dissolving rosin in an equal part of benzine. This paint dries rapidly to a hard film having a high gloss. Coal tar paints are not very serviceable when exposed to the sun, since alligatoring or checking takes place, the action of the sun causing disintegration of the tar and the formation of free carbon. This is partially overcome by the addition of Chinese wood oil and asbestine to a coal tar paint. These paints have proved very serviceable when applied to metal that is to come in contact with acid fumes, such as pipe lines or tanks in or near acid factories.

Tunnel Work. Iron in tunnel work may be protected from corrosion by the application of a prime coating of red lead or other inhibitive paint, subsequently applying an asphaltic or coal tar paint, such as those outlined above. An asphaltic paint which gives good results for this purpose may

be prepared from a heavy blown petroleum residue fluxed with gilsonite. This is dissolved in benzol, turpentine or a mixture of these solvents with petroleum distillates.

Marine Paints. Metal that is to be exposed in salt water or marshy land is subject to rapid corrosion and incrustation with marine growths. It is advisable in some cases to apply to such metal paint coatings of an anti-fouling type, which contain soaps of copper or other poisonous compounds, or which contain oxide of mercury or bichloride of mercury. Such paints are usually made upon a shellac-alcohol base, zinc and iron oxides constituting the major part of the pigment portion.

Tank and Steel Timber Paints. Iron water-tanks along roadways will rapidly corrode unless painted both on the inside and outside. A very satisfactory, hard drying paint for this purpose may be prepared by adding 2 lb of litharge to a ready mixed red lead paint. A water-resisting bituminous paint should be applied as a top-coater. Steel mine timbers which are subjected to the effect of sulphur water and gases in mines may be protected with the same paints.

General Structural Steel. Bridges, general structural steel work of all kinds, lamp-posts, letter boxes, ornamental ironwork, etc may be efficiently preserved from corrosion by the application of prepared rust inhibitive paints such as those shown below.

Red Lead Paints. When red lead is ground in oil to a stiff paste, 100 lb of the paste may be reduced with 2 gal of oil and 2 pints of turpentine drier. This will furnish a little over 4 gal of paint, containing about 33 lb dry red lead per gallon. The spreading rate of this paint will be about 400 to 500 ft per gal. The cost of the paint will be about $2.50 per gal. Red lead paste is usually made of red lead that does not contain any free litharge. Consequently, the protective quality of the red lead is reduced. The best practice is either to purchase a ready mixed red lead paint or to use pure dry red lead purchased on the following specifications, mixing the paint on the job:

SPECIFICATIONS:

1. The dry pigment to be of the best quality, free from all adulterants and not to contain less than 85% nor more than 90% Pb_3O_4, the remainder being practically pure lead monoxide, PbO.

2. It shall contain not more than 0.1% of metallic lead nor more than 0.1% of alkali figured as Na_2O.

3. It shall be of such fineness that not more than 0.5% remains after washing with water thru a No. 21 silk bolting-cloth sieve.

FORMULA FOR MIXING DRY RED LEAD PAINT:

Specification red lead	26 lb
Raw linseed oil	28 gills
Turpentine	4 gills

This will yield about 1²/₅ gal of paint costing about $1.75 per gal. For tinting this paint to a chocolate color for final coat work, add 4 oz of lampblack in oil to 1 gal of paint. This paint may be used upon all structural work.

Blue Lead Paints. Blue lead paints may be purchased in prepared form on the following formula which can be used for the priming coat on all types of structural work:

Sublimed blue lead	64 lb
Linseed oil	32 lb
Turpentine drier	2 lb

If desired, blue lead may be purchased ground in oil in the proportion of 90 parts of pigment to 10 parts of oil. For first coat work 100 parts of the paste should be thinned with 4½ gal of oil and 1 quart of turpentine. For second and third coat work, 100 parts of paste may be thinned with 5 gal of oil and 1 pint of drier. The cost of blue lead paints will average about $1.50 per gal. The spreading rate will average about 900 ft per gal.

Iron Oxide Paints. Rust inhibitive paints made upon an iron oxide base and containing from 10 to 15% of zinc chromate, red lead, zinc oxide and similar inhibitive pigments, come in prepared form ready for use. The cost is usually about $1.50 per gal and the spreading rate about 900 ft per gal. These paints are especially suited for application to tin roofs and metal siding or for general structural purposes.

Black Paints. Carbon black and graphite form the pigment base for many prepared protective paints. Litharge, red lead, silica and other pigments are sometimes added. These paints should be used as top-coaters over a thoroly inhibitive priming coat of paint. Black iron oxide is coming into use as a permanent black protective coating. In practice it has given excellent service.

Estimating Areas and Paints for Steel Structures. Chapman (9) gives the following:

"The surface area of a steel structure may be calculated by use of the following formulas in connection with the material bills giving the tonnage of the various shapes:

"Let S = square feet of surface per ton of metal, and w = weight of shape per running foot, pounds. Then, for

"I-beams: $S = (56\,800h + 54\,800)/w$; where h = depth of beam, inches.

"Channels: $S = (434b + 500)/w$, where b = width of channel, inches.

"Angles (equal-leg): $S = (660b - 21)/w$, where b = width of each leg, inches.

"Angles (unequal-leg): $S = 3220b/w$, where b = sum of widths of both legs, inches.

"Z-bars: $S = (52h + 1090)/w$, where h = depth of web (out to out), inches.

"Plates (both sides): $S = 100/t$, where t = thickness, inches."

The spreading rate of metal paints will average from 500 to 1000 ft per gal, according to the pigments used and condition of surface. Red lead paints generally average 700 ft; iron oxide paints, prepared rust inhibitive paints and blue lead paints, 900 ft per gal.

4. Prevention of Electrolysis in Concrete Structures

Paints to Prevent Electrolysis. Rapid corrosion takes place when an electric current is passed thru an iron anode immersed in an electrolyte, such, for instance, as salt water. When damp cement contains an embedded iron anode the cement acts as an electrolyte, and the same rusting action takes place, regardless of the fact that concrete contains sufficient lime to inhibit corrosion when no electrical currents are present. With the electrolytic change of metal into oxide comes an increase in volume of the products of reaction, and there is developed an enormous expansive force of mechanical pressure, which is sufficient to crack the strongest forms of concrete.

Sources of Currents. Corrosion may therefore be expected, with its attendant results, when sufficiently high voltage direct currents enter the

iron of a concrete structure, either thru contact with conductors of light and power circuits, contact with water or gas pipes carrying direct currents from grounded power lines, thru defective insulation of electrical wiring, or from similar sources. That the damage is greatest to new structures is due to the fact that the concrete is then damp and a better electrolyte than when it becomes dry from age. Much of this damage may be prevented by the adoption of suitable forms of foundation waterproofing, exterior insulating joints for pipe lines, isolation of lead-covered cables entering buildings, and other insulating devices. Of equal importance, however, should be the safeguarding of the metal with suitable insulating and bonding paints before it is embedded in cement.

Method of Making Good Bonding Surfaces. In making up specimens for test, the objection to using paints which dry upon metal to a gloss surface and which prevent proper bonding of the cement might be overcome by applying to the painted surface, while it is still tacky (not dry), sharp particles of sand or similar material. Emery powder, abrasive, and fine quartz sand have been used. When allowed to drain upon a painted rod, the particles become attached to the paint and dry with it, forming a rough surface resembling coarse sandpaper. After thoroly drying, the particles are solidly embedded in the paint, which thus presents a dull rather than a gloss film. Fine, clean, white sand was found most useful.

Tests for Bonding Surfaces. In one series of tests the specimens were made by embedding in concrete cylinders painted anodes ¾ in in diameter and 12 in in length. The rods, previous to painting, were thoroly cleaned from scale and rust. They were painted with two coats of paint. The rods were placed in 3½ in by 8 in molds, in an upright position, and a mixture of one part of Portland cement and two parts of sand was poured around the rods and tamped into place. The specimens for this series were very carefully prepared. After setting for two days, the molds were removed from the pieces, which were then aged for a month. They were then placed in water for 24 hr, and the next day were placed in individual earthenware jars containing sheet-iron cathodes, coiled so as to surround, but not touch, the cylinders. The jars were filled with sufficient water to cover the cylinders up to within 1 in of their top surfaces. The specimens were connected up in parallel and in series with resistance to reduce the voltage from 110 to 30 volts direct current. The tests were continued for 240 hr at 30 volts. The voltage was then increased to 55 and continued for 60 hr, at which time the tests were discontinued.

Test of Bonding Value. In order to determine the comparative bonding strength shown by the various painted rods with the surrounding concrete, a series of test specimens was prepared, the rods being placed flush with the bottom surface of each cylinder. After aging for three weeks, the specimens were tested in a Riehlé testing machine, being placed on an iron slab drilled thru the center with a 1-in hole to allow an entrance space for the rod in the test specimen when subjected to pressure. Each test specimen was placed in such a position that the lower end of the contained iron anode would be in alignment with the hole below. Pressure was applied until the painted iron rod was pushed away from the surrounding cement and the bond destroyed.

Observations on Results. In the test specimens where cracking had occurred the anodes showed considerable rust, the paint coatings originally applied having been destroyed. On the cathodes the paint coatings were still intact, altho some had apparently been affected by the moisture and the hydrated lime on the wet concrete, chalky surfaces being shown. Wherever there were small voids in the concrete, at or around the painted anodes, corrosion was most severe, and at such places pitting was shown. The protective coatings upon the anode and cathode bars embedded in the concrete cylinders which did not crack and which carried but little current were later found to be in a very good state of preservation.

Incidental Reactions. The breaking down of a film upon the embedded iron rods was always recorded by a sharp rise in the amperage, due to the decreased resistance offered to the flow of the current between the electrodes. The hydrogen gas formed

seemed to have a reducing or softening action upon some of the oxidized coatings, and carried to the surfaces of the cylinders considerable quantities of soft oily products, which deposited around the anodes and later hardened in contact with the air. Iron oxide was also carried to the top surfaces of some of the specimens by the action of the gas and water, and was there deposited as a dark brown stain.

Value of Well Dried and Saturated Films. Paint films that have been baked, on account of their fully saturated condition, do not act as depolarizers. It would obviously be impractical to bake paint coatings upon most forms of reinforcing metal, but quite thoroly oxidized coatings, which would probable have but slight depolarizing action, would result by allowing a period of 60 days for the drying of oil paints after application to the metal and previous to immersion in the cement. It is, moreover, possible to apply coatings which do not depend entirely upon oxygen absorption for their hardening and which contain ingredients of a fairly saturated nature. Among these could be mentioned such coatings as are composed of rosins dissolved in volatile solvents, as well as some special types of oil coatings.

Use of Pigments. The addition of a pigment to an oil usually increases the moisture resistance and makes a more impermeable film.

Conclusions. The corrosion of metal embedded in concrete structures by stray currents of high voltage is often productive of serious effects. The use of properly made paints upon such metal constitutes a safeguard that should not be neglected by the engineer. Such paints may be prepared from the following substances. The vehicle should contain: Boiled or bodied oils or products which dry to a fairly saturated film; oils which dry by semi-polymerization rather than oxidation; oils which dry to a flat rather than a highly glossy surface. The solid portion should contain a percentage of: Pigments which are coarse and which therefore tend to form films having a rough surface; pigments which are inert and which do not act as conductors of electricity; pigments which are either basic or of the chromate type. The painted metal should be sanded if possible.

DECAY AND PRESERVATION OF WOOD AND MASONRY

5. Decay, and Preservative Treatments of Wood

Causes of Wood Decay. The decay of wood is generally due to low forms of plant life called fungi which produce micelia (roots) or contain spores which are blown about by the wind. These fungi have the property of secreting chemicals which dissolve wood fiber, the wood thus serving as a food for the fungi. The chemicals evolved are termed enzymes or ferments. Various forms of insect life have a destructive action upon wood. Some of these are called borers, timber worms, etc. They bore channels into which water enters, thus destroying the wood. Mechanical abrasion is another cause of wood decay. Alkaline soils may also have some effect in the destruction of wood, but fungous growths are mainly responsible.

Effect of Seasoning. Seasoning of timber tends to prevent decay, increases durability and strength, prevents shrinking and cracking, reduces weight, and conditions the fiber for the injection of preservatives. Open air seasoning, hot air seasoning and seasoning in steam and oil are used for this purpose.

Preservative Treatments. Linseed oil paint is probably the most important wood preservative and should be used wherever possible. The film produced by the dried paint effectively excludes fungi and other causes

of decay, and, at the same time, beautifies the structure. For certain purposes, preservation with creosote and substances of a high fungicidal value is necessary. Various treatments are used for this purpose, among which is the so-called brush treatment, the preservative being applied with a brush to dry wood after air seasoning. Good results are obtained with creosote that has been heated to 180° C (356° F) before application. The preservative will penetrate about ¼ in. This treatment is cheap and convenient. By dipping the wood into the preservative, more effective results are obtained. This treatment requires a tank and is well adapted to such products as shingles, posts, poles, etc. Impregnation processes give the best results, as the preservatives are forced deeply into the wood. Impregnation processes are more expensive, however, and require considerable apparatus. They include various non-pressure, pressure and vacuum processes. The impregnation is usually deep and effective. In the open tank process, lumber is placed in a bath of hot oil in order to drive out the air, sap and water. The wood is then placed in a cold solution of preservative which is drawn in by contraction. Pressure processes, in which the timber is placed in tanks or wells containing preservatives under pressure, include the Bethell, Buehler, A. C. W., Lowry, Burnett, etc. The life of piling, road-ties, poles, cross-arms, etc, is increased greatly by these treatments. In the kyanizing process, timber is kept submerged several days in a solution of bichloride of mercury. This is not a good treatment for timber that is to be kept in a wet place where the bichloride salt would leach out.

Materials Used for Preservatives. Of the various water-soluble preservatives used, copper sulphate, mercuric chloride, zinc chloride and sodium fluoride have given the best results. Sodium fluoride has an extremely high fungicidal value. Zinc chloride is low in cost. Creosote is a very important preservative on account of its phenol content, this substance having a high antiseptic value. Various forms of coal tar creosote, water-gas creosote, wood tar creosote, mixed creosotes, etc, are used. Their value depends upon their toxicity.

For treating poles and posts, the brush treatment is effective after proper seasoning of the wood. The life of the wood may be increased five years by this method. Treatment of the ends, to a height of 20 in above ground, in a tank for five days is very effective. Coal tar creosote is often used for this purpose. Zinc chloride (5% solution hot) or other antiseptic salts may be used. Application of an oil paint will prevent leaching out of the preservative. The cost of brush treatment of 6-in posts with coal tar creosote, or impregnation with zinc chloride, varies from 3 to 6 cents. A simple form of treating tank may be made from a 100-gal iron drum mounted on a plain brick foundation which can be used as a fire-box. The preservative is placed in the tank and heated, the posts subsequently being placed in for treatment.

Painting Wood That Is to Be Preserved. Wood may be first brush-treated with zinc chloride, mercuric chloride, sodium fluoride or bichloride of mercury. Linseed oil paints may then be applied. This process is especially valuable for treatment of wood in greenhouses, dye houses, etc, where there is much moisture and heat. For rendering wood fire-retardant, it may be coated with a chemical like sodium silicate which, when heated, will fuse and retard combustion, or it may be impregnated with ammonium salts which, when heated, will liberate non-combustible gases. Sodium bicarbonate, oxalic acid, borax, ammonium chloride and ammonium

fluoride are also valuable fire-retarding salts for impregnation purposes. Paints should be applied after impregnation, in order to prevent leaching out of the salts.

6. Paints for Wooden Surfaces

Paints. The pigments which are used in paints for wooden surfaces are those opaque white pigments, such as corroded white lead (basic carbonate-white lead), sublimed white lead (basic sulphate-white lead), zinc white (zinc oxide), and leaded zinc (mixture of lead sulphate and zinc oxide). The so-called white, inert, crystalline pigments include barytes (barium sulphate), asbestine (magnesium silicate), silex (silica), china clay (aluminum silicate), whiting (calcium carbonate), gypsum (calcium sulphate). White lead, when used alone, will chalk rapidly and will often check deeply. When zinc oxide is used alone, scaling and cracking may be shown. When white lead and zinc oxide are combined, the defects of each are overcome and an excellent paint is obtained. These mixtures of lead and zinc pigments are sometimes combined with small percentages of the inert crystalline pigments mentioned above. These combinations are finely ground in pure linseed oil by machine and thinned down to painting consistency with turpentine and drier. They are sometimes tinted with color pigments, such as Prussian blue, lead chromate, lampblack, umber, sienna, ochre, etc. A good specification upon which to purchase prepared paints of the above type is given herewith.

Specifications for Prepared Paints for Wooden Surfaces adopted in 1915 by United States War Department.

The paint must be furnished in prepared form, ready for application. White paint must contain not less than 65% nor more than 70% of pigments, the balance to be liquids. The liquids shall consist of pure raw linseed oil containing a total of not over 10% of turpentine and turpentine drier. The pigment portion of the paint shall consist of white lead (basic carbonate or basic sulphate) and zinc oxide. There shall not be less than 25% nor more than 50% by weight of zinc oxide. Paints of this composition containing, in addition, not over 15% by weight in the pigment portion of such white pigments as barytes, china clay, whiting, asbestine and silica will be accepted under these specifications.

Oils Used in Paint. Linseed oil dries more rapidly and with a harder film than other types of oil, and is therefore preferred for general work. Raw oil is used in most prepared paints; boiled oil is used for special types of paint where a glossy surface is required. The normal price of linseed oil is 60 cents per gal, altho the price often goes as high as $1. Soy bean oil, which may be pressed from the soy bean, grown extensively in China and in the southern part of this country, has been proposed as a substitute for linseed oil. It is rather slow in its drying properties and requires admixture with linseed oil or a large amount of drier. Refined menhaden oil has come into some use for paints which are subjected to exposure along the coast or for special technical purposes. Corn oil and cottonseed oil dry very slowly and paints in which they are used become darkened by adherence of dust particles. Chinese wood oil, which is expressed from the nut of the Chinese tung tree, when heat-treated with the proper driers, is very valuable for certain types of waterproofing paints. Petroleum oil dries slowly and is injurious to most paints. Rosin oil disintegrates very rapidly and should not be used in paints for wooden surfaces.

Thinning Liquids. Turpentine is used as a thinner for linseed oil paste paints. It aids in the penetration and drying of the paint. High boiling point petroleum spirits, which are often referred to as mineral spirits and

Am. Soc. Test. Mat. Specifications for Oils Used in Paint

RAW LINSEED OIL
(from North American seed)

	Maximum	Minimum
Specific gravity at $\frac{15.5° \text{ C } (60° \text{ F})}{15.5° \text{ C } (60° \text{ F})}$	0.936	0.932
or		
Specific gravity at $\frac{25° \text{ C } (77° \text{ F})}{25° \text{ C } (77° \text{ F})}$	0.931	0.927
Acid number	6.00	.....
Saponification number	195	189
Unsaponifiable matter	1.50%	.....
Refractive index at 25° C (77° F)	1.4805	1.4790
Iodine number (Hanus)	.....	180

BOILED LINSEED OIL
(from North American seed)

	Maximum	Minimum
Specific gravity at $\frac{15.5° \text{ C } (60° \text{ F})}{15.5° \text{ C } (60° \text{ F})}$	0.945	0.937
Acid number	8	.....
Saponification number	195	189
Unsaponifiable matter	1.5%	.....
Refractive index at 25° C (77° F)	1.484	1.479
Iodine number (Hanus)	.....	178
Ash	0.7%	0.20%
Manganese	.....	0.03%
Calcium	0.3%	.....
Lead	.....	0.10%

which have the same boiling point and gravity as turpentine, are being widely used in place of turpentine and with exceedingly good results. Water white coal tar benzol is used in special paints and as a base for paint removers.

Specifications for Turpentine:

1. These specifications apply both to the turpentine that is distilled from pine oleoresins, and commonly known as gum turpentine or spirits turpentine, and to the turpentine commonly known as wood turpentine that is obtained from resinous wood, whether by extraction with volatile solvents, or by steam, or by destructive distillation.

2. The purchaser, when ordering under these specifications, may specify whether gum spirits or wood turpentine is desired. The turpentine shall be clear and free from suspended matter and water.

3. The color shall be STANDARD or better. The term STANDARD refers to the color recognized as standard by the "Naval Stores Trade." Turpentine is of standard color when a depth of 50 mm in a perfectly flat polished bottom tube approximately matches a No. 1 yellow Lovibond glass.

4. The specific gravity shall be not less than 0.862 nor more than 0.872 at 15.5° C (60° F).

5. The refractive index at 15.5° C (60° F) shall be not less than 1.468 nor more than 1.478.

6. The initial boiling point shall be not less than 150° C (302° F), nor more than 160° C (320° F).

7. Ninety percent of the turpentine shall distill below 170° C (338° F).

8. The polymerization residue shall not exceed 2% and its refractive index at 15.5° C (60° F) shall not be less than 1.500.

Driers for Paints. Lead and manganese in the form of oxides are boiled with oil in order to form salts or oil-soluble soaps. They act as catalytic agents in carrying oxygen from the air to the oil, thus causing rapid drying. The lead should be in greater percentage than the manganese when used together. Zinc sulphate, zinc resinate and lead acetate are other forms of driers which are used for special paints.

Paints in Paste Form. White lead contains approximately 9 lb of oil to 100 lb of paste. When used in a paint, there should be added from 4 to 5 gal of oil for reduction. Zinc paste contains approximately 16 lb of oil to 100 lb of pigment. When used, there should be added approximately 6 gal of oil or liquids.

Application of Paint to Wooden Surfaces. For the application of paint to all types of new wooden surfaces, the wood should first be sandpapered to remove the rough spots. Any knots in the wood will ultimately come thru the paint unless they are first treated by the application of a daub of turpentine or 60° water white coal tar benzol. When the knots have become softened by this application, the paint may be applied to the whole wooden surface. A bond is thus formed between the softened rosin of the knots and the paint. When the paint is in prepared liquid form, from a pint to a quart of turpentine to the gallon of paint should be added for the priming coat. This will cause greater penetration and a hard drying surface. Nail holes, grooves and cracks should then be stopped up with putty and the second and third coats of paint applied. At least 24 hr should be allowed between coats. If a week is allowed, better results will be obtained, as durability depends upon obtaining hard undercoats. When an old surface is to be repainted, any scaled, blistered or alligatored paint should be removed by sandpapering.

Paint Tests. Large wooden test structures erected by the Paint Manufacturers' Association of the United States at Atlantic City, Pittsburgh, Nashville and Washington, and painted with various single pigment paints as well as combination pigment paints, have demonstrated the superiority of the combination pigment paint. The test fence at Arlington, Va., erected by the Am. Soc. Test. Mat. has shown similar results; the report of the inspection committee for 1914 including the following statement: "The panels painted with composite paints containing both lead and zinc pigments show superiority to those painted with single primary pigments."

Comparative Durability of Paints. The addition of color pigments to white paint increases the durability at least 25%. For this reason tinted paints are preferred to white paints wherever durability is the prime requisite.

Spreading Rate and Cost of Paint. Upon new surfaces, prepared paint will usually cover from 300 to 350 ft per gal for the priming coat and from 400 to 700 ft per gal for the second and third coats. This varies with the type and finish of lumber to be painted. The cost of prepared paint averages about $2 per gal. The cost of labor is generally twice the cost of the paint.

7. Decay and Preservation of Stone and Masonry

Causes of Decay. The decay of stone is due to constant exposure to the elements, cracking caused by freezing of fissure-entrained water, seepage of water-soluble constituents, etc. Porous stones, such as sandstone, are less affected by freezing than those having capillary pores, but are not as durable as the highly non-porous stones. Granite shows a porosity of about 1%; limestone up to 10%, and sandstone up to 20%.

Preservative Treatment. Stones may be moisture-proofed by brush-coating with a solution made by dissolving 5 lb of paraffin in 100 lb of benzine. Evaporation of the benzine leaves a colorless protective coating of paraffin. Another treatment consists in applying a solution of a metallic salt, such as chloride of zinc, copper, or calcium, or the sulphate of aluminum or chromium, and subsequently applying a coating of ordinary soap which reacts to produce insoluble metallic soaps having high moisture-proofing values. Alkaline solutions of casein are also useful for this purpose. Brush treatment with coal tar, followed by daubing with hot asphalt compositions, is useful for waterproofing.

Concrete may be protected from the effect of alkaline water containing soluble sulphates, which has a marked disintegrating influence, by the application of water-gas tar. Concrete mixed with 10% of ordinary petroleum road oil is also resistant to alkalis. Portland cement-concrete structures of all types, bridges, buildings, walls, etc, may be preserved and highly decorated thru the application of prepared linseed oil paints, such as those outlined under the PROTECTION OF WOODEN SURFACES. If the concrete is damp or freshly laid, there should first be applied a 20% water solution of zinc sulphate which neutralizes any free lime present, thus preventing possible saponification. Two days later the paint may be applied. Prepared paints containing Chinese wood oil are also very useful for this purpose especially if highly glossy surfaces are desired. Waterproofing of underground concrete walls requires the application of special bituminous paints, alternate layers of felt, paper and hot petroleum asphalt, etc.

Cement Drain Tile. Cement drain tile that is to be laid in alkaline soil may be preserved from the disintegrating action of the sodium sulphate by protection with a bituminous coating. Water-gas tar is a very efficient preservative for this purpose. The drain tile may be dipped into the tar, withdrawn and allowed to drain. If desired, color pigments, such as red oxide of iron, may be added to the paint in order to give the tile a more pleasing color. Tile treated in this manner is very moisture-proof and resistant to the action of alkalis.

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SECTION 28

FINANCING OF HIGHWAY IMPROVEMENTS

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VARIETY OF PROBLEMS

METHODS OF FINANCING

EXPENSES TO BE FINANCED

ASSESSMENTS FOR BENEFIT

VARIETY OF PROBLEMS

1. The Rural District

The Highways in Rural Districts have until lately been greatly neglected owing to the facts that they were considered matters of local concern, that the mileage of roads was great in proportion to the number of abutting owners, and that the cost of their improvement was very large in comparison with the value of the property served by them. Even in such districts the conditions varied greatly. Where land was productive and intensively cultivated and where markets or transportation lines to markets were accessible, the cost of road improvement would be more than compensated for by the lessened expense of hauling due to the possibility of greater loads and better speed, but no plan had been worked out to secure such improvements. Where the land was unproductive, population sparse, and traffic light, the expense of better roads was beyond the means of the district. In either case the traffic was almost entirely local and the township, county or state did not feel called upon to bear the cost of better-

ments which did not promise to be of advantage to the entire political unit. The advent of the motor vehicle has changed these conditions. The urban population is spreading out into the rural districts, frequently to establish homes and more frequently for their pleasure riding. Improved methods of agriculture with better returns both in quantity and in prices have placed the motor car within the reach of the rural population and the demands for general highway improvement have become insistent and irresistible.

State Aid. The first response to this demand was thru state aid, the cost of road improvement being divided between the state, the county, the township, and in some cases the abutting land owners. The tendency has been to consider such improvements more and more as a general benefit and less and less a local obligation until the state itself has assumed the larger part of the burden. The rural districts, including not only those well adapted to agriculture but those where the land values are negligible and where the principal asset is the scenery, are being covered with a network of improved roads which will result in removing the isolation in which many seemed doomed to dwell and in enabling those living in the cities and towns to know the country as they had not known and appreciated it before. Whether this work should be undertaken and paid for by the state without any contribution from the locality, particularly when the needed funds are borrowed for long terms of years, is at least a debatable question which will be discussed in subsequent articles. While much progress has been made in developing systems of improved highways in the several states, much still remains to be done. In 1911 Baron d'Estournelles de Constant, in speaking of the highway situation in this country, said, "You have no real railways and highways. You think you have but you have not. You have only fragments. You have not the immense network of roads necessary for the activity and productivity of your country. Get to work; for this immense task you will never have too much money, too many men, too much time." In discussing the relative demands for new highways for purposes of business and pleasure, Clifford Richardson, in a paper presented to the Third International Road Congress held in London in 1913, distinguishes between what he calls utilities and satisfactions. In the former class he places roads which are improved in order to cheapen transportation and to bring the producer nearer to the market. In the latter he includes improvements which are prompted by the demands of automobile users and others who wish to secure good roads for pleasure traffic. He points out that motor vehicles are the principal cause of the rapid deterioration of road surfaces and that such improvements should be largely paid for by those using motor cars. If this be true, the policy prevailing in Great Britain of placing a heavy tax on gasoline or petrol apppears effectively to reach those who are responsible for the wear and tear on highways. From this source the British Government in 1913 raised more than $6 000 000, which sum was turned over to the British Road Board for use in general highway improvement.

2. The Town

In Small Centers of Population where there is a certain amount of business drawn from the surrounding country and a considerable community of interest, the situation is different. The main street or streets of the town are frequented by nearly all of the inhabitants and all have an interest in making their roadways passable and the roadsides as attractive as

possible. The improvement of the roads is therefore a matter of general public concern. Many of these towns have grown up about a village green or a public square around which, or sometimes in which, the town hall and the churches have been grouped. All of the public activities, including, perhaps, recreation and amusement, center here, and it will be conceded that the condition in which the open space, the roadways and sidewalks are kept is a matter of public concern, and it is argued that the cost of their improvement, maintenance and repair should be borne by the town. The most valuable property will be that fronting upon this square, so that if its improvement and upkeep result in special benefit to the surrounding property that property will bear a correspondingly large part of the burden. If the main street of the town needs widening, straightening, extending or a surface improvement, the benefit will again apply to the entire community. It is customary in such localities to improve one street at a time, beginning with those of greatest importance, a special tax being levied for each improvement, and in the course of time nearly all of the streets will have been improved in turn, each property owner having contributed in proportion to the value of his holdings to the improvement not only of his own but of his fellow townsmen's streets, and everybody is as well satisfied as possible where the payment of taxes is involved.

Development of a Street System. But as the town grows the number of what are called main streets increases; other centers of activity or recreation are needed. The new projects will still result in some general benefit but in a large measure of special benefit. The effect upon the property in their neighborhood will be proportionately greater and more exclusive than in the case of the first village green or town square. The entire community will doubtless feel the benefit of the new improvements but in less degree, as they tend to create new centers and diffuse rather than concentrate business and other activities. The town can still afford to contribute toward the expense, but the fair portion to be assumed by it will be less in proportion to the amount of special benefit resulting to the particular locality.

Improvement of Pavements. With this growth there is a demand for a more substantial character of pavement on the principal streets. The broken stone or gravel which formerly answered every purpose must be replaced by a smooth surface, such as bituminous or brick, and while the interest of the entire town in such an improvement is still keen, the benefit is somewhat more localized and the owners of property on streets some blocks away who use the original main street less frequently are more reluctant to contribute towards the cost of the new pavement. To avoid the burden of a special tax, resort is likely to be had to a loan which seemed such an easy way to raise money to pay for the water supply or sewers which may have already been installed, and the policy of borrowing instead of paying cash for street improvement is inaugurated.

3. The Small City

The Small City, as the term is here used, is one of less than 100 000 population. The transition from the town to the small city is gradual and the line of demarcation between the two is indefinite. There are instances of towns of 15 000 or 20 000 inhabitants which are called villages and are governed by the administrative machinery common to villages, while many so-called cities are far less populous. In many of these centers of

population, whether they are called villages or cities, the community of interest, characteristic of earlier days, still persists. It is when this common interest is chiefly concerned with the larger activities and enterprises, such as water supply, police and fire protection, the disposal of wastes, and the care of dependents, incompetents and criminals, while those whose benefits can be localized attract increasingly less general attention, that the town is classified as a city. There will be a limited number of streets in which most of the business will be carried on and the condition of them will continue to be a matter of general concern. The people will have become accustomed to increasing annual tax budgets and will not scrutinize them as closely as they did in the village days; they will probably have resorted to the use of the city's credit in order to raise funds for various purposes and the annual burden of providing interest and sinking funds for their obligations or for retiring such serial bonds as may have become due will not have become so serious as to deter them from further use of the city's credit in order to provide new pavements.

Special Assessments or Loans. Those who have seen other streets improved one after another from the general town funds and have contributed their share toward the expense will resent being called upon to pay for their own pavements. It will not be until the demands upon the city's revenues for other general purposes have increased to such a degree that they see the annual tax budget growing at a rate considerably greater than the population that the necessity of levying special assessments for every improvement which results in distinctly local benefit will be realized. The small city may, after much discussion, have resolved to undertake the construction of some important boulevard or parkway in connection with the development of a park system, or it may have decided that it, like some of the larger cities, should create a civic center, and the interest in either or both of these projects will be so general that, while the idea may be encouraged by those whose property will be required for the purpose or who may own property which will be substantially increased in value, the reasonableness of imposing a special share of the burden upon property so affected is seldom suggested and the only method of financing seriously considered will be by another loan for which the credit of the city will be pledged.

4. The Large City

Development of Large Cities. The large city is frequently created by the consolidation of a number of towns and villages and in it all of the conditions described in the two preceding Articles will be found. The present City of New York, when established, included what were previously three cities and a score or more of towns and villages. To administer the affairs of these different communities under uniform laws which had been evolved to fit conditions existing in the largest city of the United States was one of the most difficult problems in city government that had ever been presented. There have been certain instances of municipal coöperation, as in Boston, where a number of cities and towns have been brought together within a metropolitan district for the exercise of such functions as the development of park, water supply, and sewerage systems, but where they retain their autonomy in the administration of their local affairs, among which is included the construction, maintenance and repair of their highways. Even in London there are 29 city or borough governments within the administrative county, each one of which determines

what sums it shall spend in the care of its streets, altho the London County Council exercises jurisdiction over certain arterial highways and contributes to the expense of their improvement.

Local and General Assessments. Where highway administration is centralized and conducted under laws which apply to the entire city, parts of which are intensively developed, others suburban and still others rural, some very difficult problems will arise. Streets in the older parts of the city may have been paved and repaved with substantial pavement at the expense of the abutting owners until it is believed inequitable to ask them to pay for any more surface improvements, and laws may have been passed forbidding further paving assessments where a modern pavement has once been laid and paid for by local assessment. The taxpayers in a suburban district, where the streets may have been improved in the manner described in Art. 2, are likely to insist that they, too, have paid for road surfaces which were adapted to their needs and, inasmuch as they are called upon to contribute to the cost of pavement renewals in the older parts of the city, they are entitled to the same consideration. In the undeveloped sections where no pavements have yet been laid, efforts will be made to secure for the first pavement the cheapest type which can be constructed and which will still exempt them from further assessment.

Classification of Pavements. In New York, where there is a prohibition against assessments for repaving, an attempt has been made by statute to meet such cases by classifying pavements into those which are permanent and those which are preliminary, the term permanent not being used in a literal sense but as indicating the character of pavement which will exempt the abutting owners from further assessment.

New York Charter Provision. "Pavements which were laid or authorized between January 1, 1898, and June 20, 1910, the cost of which was assessed upon the property deemed to be benefited, and pavements, the cost of which was paid for by assessment, or by the owners of adjoining property, or by local taxation, or by bond issues paid by the locality prior to January 1, 1898, shall be deemed to be permanent pavements. No street or portion thereof, that shall have been paved with a pavement deemed a permanent pavement or that hereafter may be paved with a permanent pavement paid for wholly by assessment shall be repaved at the expense of the adjoining property owners, unless a majority of the owners of the property on the line of the proposed improvement shall petition for such repaving at their expense by assessment. Whenever a street paved with a preliminary pavement shall be repaved, the repaving shall be done with a permanent pavement, unless the owners of property on the line of the proposed improvement petition the Local Board having jurisdiction for a second preliminary pavement, to be laid at the expense, by assessment, of the adjoining property owners, and in such event a second preliminary pavement shall be laid if said Local Board so orders, and the Board of Estimate and Apportionment consents. Whenever a permanent pavement shall be laid to replace a preliminary pavement laid, in whole or in part, at the expense of the property owners by assessment or to replace a permanent pavement laid at the expense, in part only, of the property owners by assessment and the cost of the replacing pavement shall exceed the amount assessed upon the property deemed to have been benefited for the pavement replaced, the excess of such cost shall be assessed upon the property deemed to be benefited, and the balance of the cost of the replacing pavement shall be borne and paid by the city; but in no case shall

the cost of a second or subsequent preliminary pavement be so deducted from the amount to be assessed for the laying of a permanent pavement. The class of a pavement shall not be changed after the same is laid."

Classification adopted by the Board of Estimate and Apportionment acting under authority given by the act.

Permanent pavements. The following pavements laid on a Portland cement-concrete foundation 6 in or more in thickness: Stone block, wood block, asphalt block not less than 3 in in thickness; sheet-asphalt with wearing surface not less than 2 in in thickness and binder not less than 1 in thick, vitrified brick and iron slag.

Preliminary pavements. Stone block on sand foundation, asphalt block not less than 2 in in thickness laid on a cement-concrete foundation not less than 4 in thick, sheet-asphalt laid on a cement-concrete foundation not less than 4 in thick, bituminous concrete and bituminous macadam; also cement-concrete and water-bound broken stone, not less than 6 in thick. under conditions to be prescribed by the Board. It will be seen that the statute arbitrarily classifies as permanent all pavements which were laid before a certain date and paid for in a certain manner with no regard whatever for the foundation, the materials used or the character of the work.

Boulevards and Parkways. Every large city has certain wide streets which are described as boulevards or parkways, the improvement of which is usually carried out at the expense of the city at large under the theory that they are of general benefit. Such streets and even others which, by reason of their widths and positions, are by no means exceptional are sometimes placed under the jurisdiction and control of the park authorities for the sole reason that they may, as a result of such control, be improved at general expense and the abutting owners may escape the burden of assessment which, under other circumstances, would be placed upon them.

Streets in the Office Building, Shopping and Hotel Districts are so generally used that it is commonly conceded that their repaving is a proper charge against the city as a whole. It is true that the most expensive property in the city and the greatest producers of revenue from taxation are found in those districts and their contribution to the general city budget is so large that it is reasonably argued that they are entitled to exemption from local assessment for the replacement of pavements. But the demands upon the city's resources are so great that repaving cannot always be done as promptly as it is actually needed. The value to such property of thoroly good, smooth and quiet pavements is so great that the cost of such frequent renewals as would always keep them in the best of condition would, if imposed entirely upon the owners, be trifling in comparison with the added attractiveness to tenants, shoppers and guests and the increased rentals which the property would command.

5. Responsibilities of the Highway Engineer

Province of the Highway Engineer. The preceding outline of the general problems of financing highway improvements and the more specific discussions in the following Articles may be thought to be outside the province of the highway engineer. There is a notion quite generally prevalent, even among engineers themselves, that their proper function is to plan and execute the work, but that the duty of determining general policies,

more particularly those relating to financial considerations, belongs to the administrative heads of the highway department whether of a state, county, township or city. Such officials are commonly appointed for brief terms of office or, when the term is nominally longer, some excuse is quite frequently found for terminating it after a change in administration. Each new commissioner or superintendent, or whatever he may be called, will have some ideas of his own even tho, as is too frequently the case, he may be entirely inexperienced in this kind of work. His ambition is to impress these ideas upon the organization of which he is the head for the time being and he may think it especially desirable to discredit the acts and policies of his immediate predecessor.

The Highway Engineer as a Subordinate. The engineer, who, tho likely to be continued in office, is merely a part of the permanent organization, is quite likely to accept the new ideas as to organization or methods of financing as an incident to a change of administration, even tho he knows them to be essentially unsound. Should he allow what he knows to be unsound financial methods to be adopted without entering a vigorous protest? If contracts and specifications were prepared that would be obviously wasteful or needlessly expensive or would probably result in damage claims or litigation which would increase the cost of the work, he would doubtless feel it his duty to point out their defects. There is no reason why he should not similarly protest against unsound and reckless plans for the financing of highway improvements. His advice may not be taken the first time such objections are made, but they should be placed on record and when their soundness shall have been demonstrated his next protests are likely to receive more consideration. Engineers appear altogether too timid about discussing such features of their work in their periodical reports. They are usually ready enough to discuss what are commonly admitted to be the strictly engineering features of their work and are beginning to include such subjects as the organization of the engineering staff and cost data, but the questions of how the state or the city or the individual property owner who is benefited is to pay for the work, the relation of the life of the road or pavement to the period during which it is to be paid for, and just what this means to the state, the city or the individual, are subjects which he discreetly avoids. His experience should, however, render him peculiarly well qualified to discuss and advise upon these subjects. There have been frequent instances of the greatest recklessness in financing highway improvements, and in many cases these questions have been determined by legislative enactments before the engineer has had any connection with the work. Such improvements are now being carried out on a much larger scale than they formerly were and by organizations which are in existence and well developed and which have ample opportunity to impress their ideas upon the entire project in its financial as well as its engineering features.

Responsibility of Highway Engineers. The engineer has a distinct responsibility for every phase of the work and he should not shirk it. If the road-improvement or street-paving policy is discredited thru bad financing or an unjust distribution of the burden of expense, if the funds are used to create an extensive system of highways and nothing is left to care for them after they are built, if the people who are now insistent upon highway improvement find that the roads and streets are worn out years before they have finished paying for them, the public may conclude that the benefits they expected are not worth the price they have to pay and

will refuse to go further. The engineers as well as the administrative officers will suffer from such an unfortunate situation, so that self-interest as well as professional pride should prompt them to assume a stronger position than they have heretofore taken with respect to this phase of the highway problem.

METHODS OF FINANCING

6. Long-Term Bonds

Present and Future Benefit. The argument most frequently advanced against the assessment directly upon the abutting property of the cost of highway improvements is not only that all street improvements are of general benefit but that the benefit will inure to the next generation as well as to the present owners, and that the next generation should therefore share the burden. This argument is made not only with respect to the acquisition of property for new streets and for the widening and straightening of old streets, which are permanent improvements, and for grading, surface drainage, culverts and bridges, which are reasonably permanent, but also for the cost of the pavement itself. The most effective way to accomplish this transfer of the burden or a greater part of it to someone else is to raise the money required for the improvement by the issue of bonds, and the temptation is to make these obligations run for a long term, frequently 50 years.

Increased Cost when Bond Issues are Used. With interest at 4 or 4½%, as has frequently been paid, the total interest payments would be twice or two and one-quarter times the actual cost of the work. The annual amortization charges for 50 years on a 3% basis would be 0.89%, so that for every $1000 of original cost the city or the state would pay $2445 in the case of 4% bonds and $2695 in the case of 4½% bonds. But the roadway surface will have worn out long before the expiration of the 50-year period, yet the public at large will keep on paying. If this apparently easy way of paying for street improvements is once begun it is likely to be continued and to be applied to the payment of the cost of replacing worn-out surfaces. There are many cases where pavements on country roads and city streets will not last more than ten years, and if this policy of financing is continued the public will after 40 years be paying for five different pavements, four of which will have entirely disappeared, and the annual expense during the decade from 40 to 50 years after the original pavement was laid will be 24.45 or 26.95% of its original cost, depending upon whether the bonds carry 4 or 4½% interest. The above estimates relate only to the surface pavement itself and not to the more permanent portions of the work which will have a life much greater than 10 years. In the case of rural highways the results of this policy are equally startling. Road improvements which are now being carried out in many states cost from $12 000 to $20 000 a mile and in some cases even more. With state bonds bearing 4% interest, the total interest and amortization charges for a period of 50 years will amount to $29 340 or $48 900 a mile for an initial cost of $12 000 or $20 000. This would amount to from $46 to $76 an acre for all of the land within half a mile on each side of the road. Such roads are commonly 16 ft wide, which is equivalent to 9387 sq yd of surface per mile of road, and the surface of bituminous macadam roads of the type in common use may be assumed to cost an average of 5 cents a sq yd

for maintenance and repair during the first 10 years, and to require complete resurfacing at the expiration of that period. Assuming that such resurfacing costs 60 cents a sq yd, the cost of maintenance for five 10-year periods and of four renewals would amount to \$4.90 a sq yd or \$45 996.30 a mile. If this be added to the total interest and amortization charges, the cost of these roads before they are finally paid for would be \$75 336.30 in the case of a road which originally cost \$12 000 a mile, or \$94 896.30 if the initial cost were \$20 000 a mile, these totals amounting to \$118 or \$148 an acre for the area extending ½ mile on each side.

Bond Issues for Surface Renewals. If the state were to raise the funds for the decennial renewals by 50-year bonds instead of providing it in the annual budget, it would at the end of 50 years have saved \$22 528.80 a mile in direct appropriation for four surface renewals but it would have paid \$27 541.46 in interest and amortization charges, making the total cost of the road \$80 348.96 or \$99 908.96 a mile, which is equal to \$126 or \$159 an acre for the area already described, while there will still be the sum of \$27 541.46 a mile in interest and amortization charges on the funds borrowed for periodical renewals which will not be entirely paid off for another 40 years.

Relation of Total Cost to Land Values. The acreage value of the land along such roads will be far less than the sums above named, while the system of financing road improvements in this manner is so monstrously absurd that it is surprising that it should even have been considered. Yet great cities and states have started comprehensive schemes of street and road improvement on this very basis. The folly of such a policy will undoubtedly be apparent before they have gone much further.

7. Short-Term Bonds

Advantages of Short-Term Bonds when issued for highway improvement may be generally considered as those whose term will approximately correspond with the life of the improvement for which the funds are to pay, so that the road will not be worn out before it is completely paid for. Some portions of the work will last longer than others, and bonds which will correspond in their term with the average life of the improvement may properly be considered short-term bonds. In the case of a road improvement which is to be entirely paid for by bond issues, if 20% of the cost is represented by such expenses as widening, grading and substantial culverts, that portion may be considered as virtually permanent, and 50 years would not be an unreasonable time in which to pay for it; if 20% were for curbing and for gutter paving which might be expected to last for 20 years, bonds issued for a corresponding term for this part of the work would be fair and reasonable; if the road surface represented the remaining 60% of the cost and the surface would require replacing in ten years, it would be unwise to borrow the money to pay for that part of the work for a longer period. The average life of the entire improvement might in such a case be considered 20 years and it might therefore be considered fair to issue 20-year bonds to pay for it. There is a fallacy, however, in this argument as the interest and amortization charges will be constant for the entire 20-year period, notwithstanding the fact that a part of the work, representing 60% of the total cost, will have been worn out in half that time, altho there will still remain a portion representing 20% of the

total cost which will last for 30 years after it is entirely paid for. A more conservative plan would therefore be to limit the bonds to 15 years for improvement of the kind described.

Annual Payments for Interest and Sinking Fund. In cities, the cost of the first pavement is commonly assessed upon the abutting property and the city at large pays for replacements, and the funds for the purpose are almost always raised by bond issues. While the life of such pavements varies greatly, depending upon their character, the kind of foundation used, and the intensity of the traffic to which they are subjected, it is probable that their average life will not exceed 15 years, and this period seems a logical one for the term of the obligations which may be issued to provide funds for their construction. Amortization charges for this period on a 3% basis amount to 5.38%, while bonds for so short a term will probably carry 4½% interest at the present time, making the total annual contribution to care for them at maturity 9.88%. If the bonds are for but 10 years and carry 4½% interest, the annual payments for interest and sinking fund would be 13.22%. As the terms of the bonds are shortened, the total annual expense grows impressively larger but it must be remembered that there is less overlapping of the different issues and, after this policy of paying for highway improvements by bond issues has been followed for a period corresponding with the term of the bonds, the total amount to be provided to care for the outstanding debt will be considerably less in the case of the short-term bonds. For instance, if a constant sum of $200 000 a year were borrowed for highway improvements and if 50-year bonds were issued for the purpose, at the end of 50 years there would be $10 000 000 of these bonds outstanding, and during this time the annual interest and amortization charges would gradually increase until it reached $489 000, when it would remain constant. If, however, the funds were raised by the issue of 10-year bonds, there would be $2 000 000 outstanding at the end of 10 years, during which time the annual interest and sinking-fund charges would increase until at the tenth year they reached $264 400, when they too would remain constant. Under the latter policy there would at the end of 50 years be an annual saving to the taxpayers of $224 600 a year. It may be said that these periods are so long that such a discussion is academic, but street and road improvements are going to continue for an indefinite time, our cities and states hope to remain solvent and must meet their financial obligations, and debts of this kind must be paid in full, so that the actual facts should be squarely faced.

Need of Control over Methods of Financing. In the United States there is no limitation placed upon the terms for which our cities and states can borrow money other than the willingness of the investing public to take their obligations. The need of some controlling authority is becoming obvious. This frequently exists in other countries. In Great Britain it is vested in the Local Government Board, which is a Cabinet department and the consent of which is required before any city, town or county can issue its debentures. All of the facts must be submitted to this Board, including a statement of the purpose of the loan, a description of the improvements to be undertaken, an estimate of the cost, and the probable life of each particular part of the work, and the Board in giving its consent specifies the term for which the funds may be borrowed, such term corresponding as nearly as possible with the reasonably estimated life of the structure or work.

8. Serial Bonds

Advantages and Disadvantages. To distribute the cost of street or road improvements over a term of years and at the same time to avoid the necessity of accumulating large sinking funds which return small rates of interest, resort is frequently had to serial bonds. In this case provision must be made for retiring a certain part of the issue each year and for interest on the bonds which remain outstanding. If $100 000 of 4% bonds are issued in serial form, $4000 falling due each year, the provision which must be made to care for bonds to be retired and interest on those outstanding will be as follows: first year, $8000; eleventh year, $6400; twenty-first year, $4800; twenty-fifth year, $4160. One advantage of this plan is that as part of the work is worn out and the value of the improvement becomes less there is a corresponding reduction in the annual burden. It is important, however, that the series shall be so arranged that the amount outstanding at any time shall not exceed the actual value of the original improvement at that time. When serial bonds are issued in such a manner that the last bonds will not be retired for a long term of years, or a term far in excess of the probable life of a large portion of the work, the plan is uneconomic and pernicious.

Maine Plan. A novel scheme for financing road improvements is that adopted by the State of Maine. Under a law enacted in 1913, serial bonds, the last of any series being payable within 41 years, were authorized to be issued in amounts not exceeding $500 000 in any one year, with the provision that not more than $2 000 000 of these bonds should be outstanding at any one time, the bonds bearing interest not exceeding 4%. The extraordinary provision of this law is that these bonds are to be cared for from the receipts for automobile licenses. With $2 000 000 of bonds outstanding and one-fortieth of this sum to be retired in any one year, $130 000 would have to be provided annually for interest on the outstanding bonds and for the retirement of those falling due. In 1912 the receipts from automobile license fees was about $100 000. This sum was increased the following year to $140 000 and in 1914 to about $180 000. If these increases continue there would appear to be some margin which could be devoted to the annual expenses of the repair and maintenance of these roads, but the capitalization of estimated receipts from this source, which prudence would dictate should be devoted to upkeep, appears to be a dangerous method of financing road improvements, especially in view of the fact that it is highly probable that, before the last of any series will be retired, it will become necessary to replace the road surface several times, and to meet this expense the entire receipts from automobile licenses over and above the amount required to care for the bonds would doubtless be required, and even this would probably be found inadequate.

Maryland Plan. In marked contrast with this is the policy of the State of Maryland, which is paying for its highway improvements by 15-year bonds, so that when the road surfaces are worn out there will be little, if any, outstanding debt incurred on their account, provided that such renewals of the surface as may be required before that time are paid for from general appropriations.

Application to County-Road System in Illinois. An excellent illustration of the use of the serial-bond plan to finance a system of highways is that adopted by one of the counties in Illinois, where 4% bonds to the amount of $1 500 000 have been authorized for a system of county roads; $75 000

worth of these bonds is to be retired each year so that at the end of 20 years the roads will have been paid for. It has been estimated that the annual cost of providing this road system per acre of farm land, which has an assessed value of a little over $30 an acre, will be a maximum of 10⅛ cents in the third year, when the entire improvement will have been completed and the interest charges reach a maximum, and that this will gradually decrease until in the twentieth and final year the cost for each acre of farm land will be but 6⅝ cents.

9. Annual Appropriations

Changing from Credit to Cash System. When highway improvements are not paid for with borrowed money, that is, when they are paid for in cash, resort must be had to taxation, the amount to be expended each year being included in the annual budget. It is apparently so much easier to pay with borrowed money with the idea that the next generation should share the expense, and those responsible for budget making are so sensitive to the criticism that invariably follows an increase in the tax rate, that it is difficult to secure adequate budgetary appropriations for highway improvements. After a long period of borrowing and when provisions for interest and sinking-fund charges represent a large part of the annual tax budget, the need of a change of policy becomes obvious, but with a long period of payments on outstanding obligations to look forward to it is difficult to change to such a basis.

New York's "Pay-As-You-Go" Plan. The City of New York has issued its bonds to such an extent that the debt service, or the annual interest and amortization charges, amounted to 37% of the total sum raised by taxation in 1914. A change in policy was then determined upon to be brought about in 4 years in the following manner: For all revenue-producing enterprises, such as water supply, transit lines and improvements of the water front, 50-year bonds are to be issued as heretofore; for all non-productive improvements, such as repavements, bridges and public buildings, three-fourths of the funds required during 1915 are to be raised by the issue of 15-year bonds and one-fourth by short-term loans provided for in the tax budget for the following year. During the year 1916 one-half of the funds needed for these purposes are to be raised by the issue of 15-year bonds and one-half by short-term notes provided for in the budget for the following year. In 1917 one-fourth of the requirements will be met by the sale of 15-year bonds and three-fourths will be paid for as above described, which is equivalent to cash; while in 1918 and thereafter the entire expenditures for non-revenue-producing improvements will be paid for without incurring any bonded debt. Inasmuch as a very large proportion of the outstanding debt of New York City will run for from 30 to 50 years, the debt service budget will decrease very slowly and the change to a cash basis will necessarily involve a substantial increase in the tax rate. This is a fair illustration of the difficulty of changing from a credit to a cash basis in financing improvements which do not produce any direct revenue.

Prompt Completion of Highway System. In small cities, where the mileage of pavements is small and a considerable annual expenditure for replacements is not needed, the advantages of budgetary appropriations are not so obvious, but in a large city or a state, where the annual expenditures are likely to run into the millions, they are quite apparent. It was shown

in Art. 7 that in 10 years after the commencement of yearly issues of 10-year bonds the annual debt charges would exceed budgetary appropriations to the same amount by 32.2%, while in the case of 50-year bonds it will be found that 20 years after beginning to raise funds in this way the interest and sinking-fund charges will almost exactly equal the annual cash expenditure and from then on it will exceed it by an increasing percentage every year for another 30 years. Ten or even 20 years are very short periods in the life of a city. The creation of a state system of highways is somewhat different. There are insistent demands that such a system be developed within a very few years. Annual appropriations to the amount required to provide such a system in, say, 5 years would be out of the question. The people of the State of New York, for instance, voted $50 000 000 of bonds for highway improvements in 1905 and another $50 000 000 in 1912, all of these bonds running for 50 years. If they pay 4%, this will mean an annual tax of $4 890 000 for interest and sinking-fund charges for two generations, to say nothing of the huge budget required for maintenance and periodic renewal of the road surfaces. Yet annual appropriations of this sum would have provided the same system of improved roads in 20 years and there would have been no debt saddled upon the next generation. The immense sum authorized to be raised by bonds could not be effectively expended in less than 10 years, or half the time within which the entire improvement could have been carried out at no greater annual burden and without a dollar of debt.

10. Local Assessments

Roads. In view of the enormous demands upon the resources of cities and states for purposes which are of general benefit, it is necessary either to find new sources of revenue by means of special taxes or to raise at least a part of the cost of improvements which are of local benefit by direct assessment upon the property so benefited. Few, if any, improvements involve so large a proportion of direct benefit as those relating to highways. In the rural districts the property fronting upon the roads is of such relatively low value that assessments for any considerable portion of the cost of their improvement cannot be imposed upon it, but the county and township could properly be required to share the burden with the state and a small assessment could with equal propriety be placed upon the land fronting upon the road. This was the theory of the first state aid laws and it was so sound and just that it seems unwise to have abandoned it. Improvements under this law, however, were initiated upon petition and the improved sections of road were not contiguous, while the demands were insistent for a complete system of good roads traversing the state in all directions, and to meet these demands the state itself was obliged to undertake the task of providing a comprehensive system of good highways without depending upon the local authorities.

Streets. In cities the conditions are different. The abutting property is so valuable that the cost of good pavements is but a small proportion of the land values, while that value is at once further increased as a result of the improvement. In most large cities the entire cost of the first pavement is assessed directly upon the property, and in some cases the cost of repaving is similarly assessed. In Rochester, N. Y., the entire cost of all pavements, both original and repaving, is assessed upon the abutting property. In Utica, in the same state, one-third of the cost

of the original pavement and the subsequent renewals is borne by the city and the remainder is assessed according to benefit. In the American City, November, 1914, there is a compilation of the method of assessing the cost of acquiring new streets, of widening existing streets, and of surface improvements. While in the smaller cities the cost of the first paving is often paid by the city at large, Washington, D. C., is the only city of considerable size that follows this practice, and conditions in this city are so exceptional, owing to its very wide streets, that it cannot be taken as typical. The benefit of good pavements to the abutting property is so great that the cost of substituting a new surface for one which is worn out could often be assessed upon the abutting property without great hardship. Where such property has a very high value the expense of periodic repaving of the streets upon which it fronts would actually be much less than its share of the general expense if paid by the city at large, whether by budgetary appropriations, short-term bonds, or long-term bonds. New York City, with its enormous expenditures for pavement replacements and its very high real-estate values, may be exceptional, but an analysis of the cost to individual property under several methods of financing repaving will show startling results. It is assumed that the first pavement laid will have been provided with a substantial foundation which will serve for several subsequent surfaces. The prevailing prices for pavements of different kinds are used and the life of the surface is estimated to be from 10 to 18 years, according to traffic conditions, and the cost of each new pavement is divided by the years of its estimated life, each parcel being charged with the paving of one-half the roadway of the bounding streets, except the space between surface railway tracks and 2 ft outside of the rails, which is cared for by the traction companies. It is also estimated that the city will expend $5 000 000 annually for repaving, and the share of the particular property of the interest and sinking-fund charges is that which would be called for at the expiration of a term of years equal to the terms of the bonds.

An Office Building occupying an entire block bounded by four streets, is assessed for taxation at $12 425 000. The cost of renewing the pavements on each of these four streets at the expiration of their reasonable life if made in equal annual payments would be $354 a year, while the share of this property of a $5 000 000 annual appropriation would be $7970.64, and its annual contribution on a 10-year bond and 50-year bond basis respectively would be $10 536 40 and $19 482.40.

A Club House occupying a corner fronting on two streets paved with asphalt has an assessed value of $115 000. The annual expense to it of replacing pavements at the end of their reasonable life would be $30.56, while its contribution to a $5 000 000 annual appropriation would be $73.77, and its share of the same provision for repaving on the basis of 10-year or 50-year bonds would be $97.52 or $180.32.

A Private Residence with a Frontage of 100 Ft but not a corner, and extending thru the block, and thus fronting upon two streets, is assessed at $115 000, and the cost to it of pavement restoration by direct assessment would be $36.12 annually, while its contribution toward the other methods of financing repaving would be precisely the same as that of the club referred to above, its assessed value being identical.

A Block of Eleven Attached Houses located on a corner is assessed at $260 000 and its share of repaving by direct assessment would be $94.40 annually, while its contribution to annual appropriations, 10-year bonds, and 50-year bonds would be respectively $166.79, $220.48, and $407.68.

A House Occupying a Lot 20 Ft Wide in a street accommodating a double-track surface railroad has an assessed value of $10 000. The cost to it of repaving the space not cared for by the railroad company would be $2.40 annually, while its share of annual appropriations, 10-year bonds, and 50-year bonds would be respectively $6.41, $8.48, and $15.30.

A Small Detached House on a 40-Ft Plot fronting on a street 60 ft wide has an assessed value of $4200. In this case its share of renewal of an asphalt pavement by direct assessment would be $5.55 a year, while its contribution toward annual appropriations, 10-year bonds, or 50-year bonds would be respectively $2.69, $3.56, or $6.59.

Financial Advantages of Direct Assessments. In all of the instances above cited, except the last, it will be cheaper for the property to pay a direct assessment for renewing the pavement on the abutting street than to pay its share according to its taxable value of annual appropriations, 10-year bonds, or 50-year bonds. With respect to the modest detached house on a 40-ft plot, it is not improbable that by the time the first pavement is worn out and it is necessary to replace it, the assessed value of this property will have increased to such a point that even in this case its share of the burden of restoring pavements with borrowed money will be less than if it were assessed directly for the expense of replacement.

11. Reckless Financing

Methods of Reckless Financing. References have been made in the preceding Articles to methods of financing highway improvements which without exaggeration may be called reckless. To borrow money to construct roadway surfaces which will wear out long before they are paid for, to apply the same methods of financing to the portions of a road or street improvement which are permanent or which will last for a long period of years, and as to those portions which will be short-lived, to spend large sums for construction without proper provision for maintenance, to save on foundations and drainage when they are necessary to insure a reasonable life for the roadway surface, to use or to capitalize receipts which should be devoted to maintenance and divert the funds to new construction without provision for upkeep, to embark upon any extensive scheme of highway improvement before the ultimate cost has been carefully estimated and a definite plan has been worked out, not only for progressive construction but also for maintenance, all or any of these show lack of good business sense and, judged by these standards, many, if not most, of the extensive highway improvements which have been undertaken are characterized by a certain degree of recklessness.

General and Isolated Improvements. The value of a system of improved roads depends upon its completeness and the continuity of the various routes and in no small degree upon the promptness with which the entire system can be created. The more complete the system and the better the articulation the greater the general benefit, and hence the justification for a resort to general taxation whether by annual cash appropriation or by borrowing for a reasonable term of years. Where isolated pieces of road are improved and the direct connections between them are not provided the benefit cannot be general and resort to general taxation or loans cannot be justified. There have been numerous instances of recklessness in financing highway improvements which by comparison make any of the methods heretofore described appear extremely conservative. Several examples will be cited.

A Flagrant Case of Term Bonds Unloaded upon a City. In 1865, the Legislature of the State of New York authorized three of the towns of Westchester County to raise by loan the sums of $3500, $6500, and $2500 respectively, which sums were to be appropriated to "making, grading, extending and regulating" a certain highway beginning at the Harlem

River and passing thru the three towns named. The act provided that each town should issue bonds for the amount required to meet the cost of that part of the improvement within its limits and that these bonds "shall bear an interest of 7% per annum payable annually, and they shall be so drawn as to become due in sums not exceeding $1000 in any one year." This means of securing the improvement of what was then a main highway appeared reasonable enough and it seemed probable that whatever debt might be incurred would soon be liquidated. In 1868, however, the law was amended by substituting for the sums named for each town the words "such sums as may be necessary." The town which was first authorized to spend $6500 actually expended, or at least raised by issuing its bonds, the sum of $112 500, some of these bonds being in denominations of $1000 but the greater portion of $500 each. There were altogether 178 different bonds, the last one of which will become due in the year 1980. The town which was originally authorized to issue $3500 in bonds actually issued its bonds to the amount of $278 000, all of these having apparently been in $1000 denominations, as the last one will fall due in the year 2147. The two towns above referred to have since become a part of the City of New York and that city has been obliged to assume all of the obligations of the towns, so that in New York's tax budget there appears each year provision for paying off one of the bonds of each of these towns, together with interest at 7% on those which remain outstanding; that is, while the first act provided that two towns, now part of the City of New York, should incur a debt aggregating $10 000 which was to be entirely paid off in not more than 13 years, an actual debt of $390 500 was incurred and saddled upon the City of New York in such a fashion that it could not be entirely paid for 278 years after the first bonds were issued.

Bonded Debt Incurred Two Days before Annexation to a City. One of the towns of Kings County was to be annexed to the then City of Brooklyn on July 1, 1894. Acting under authority of a special statute, that town issued its bonds to the amount of $500 000, and on June 28th, 3 days before it went out of existence, the town authorities made a large number of contracts for road improvements consisting for the most part of water-bound broken-stone roads. The act provided that the town bonds should be issued as serial bonds in groups of $100 000 each, the first of the bonds falling due not less than 10 nor more than 11 years from the date of issue and being retired in 50 successive annual installments. The funds required to meet the interest on the outstanding bonds and the payment of those due was to be provided for in the tax levy of the town every year, there being no assessment upon the abutting property. The town as a separate political unit ceased to exist 3 days after the contracts were made but the city of which it became a part was obliged to assume the obligation, altho it was enabled to provide the needed funds by imposing a special tax annually upon the property within the former town, which became a separate ward of the city. It is safe to say that little, if any, of the roadway surface constructed under this act was in existence when the first bonds of the several groups became due but the debt will not be fully paid until the year 1954.

Other instances of reckless financing might be given, but these two are sufficient to demonstrate the enormous price which will sometimes be imposed upon one or more succeeding generations in order to avoid cash payments for improvements which are obviously of immediate benefit to a particular locality.

EXPENSES TO BE FINANCED

12. Investigations and Surveys

Preliminary Investigations. The physical improvement of roads and streets is not the first work to be undertaken or the first expense to be incurred. When a general scheme of improvement has been decided upon there is usually a feverish desire to begin work on the ground or " to make the dirt fly." The public and the press are insistent that something shall be done that they can see, and they apparently fail to understand that, if the money is to be wisely expended, thoro preliminary studies are necessary. If a state is to devote millions of dollars to general highway improvement, the first thing to be undertaken is a thoro study of the organization best suited to carry out the work; then should come a careful examination of the existing highway system with a view to the selection of the routes which will be of the greatest benefit to the general public. Following this will come investigations and studies to determine where and to what extent modifications of alignment and grade are needed. Before contracts are made there should be a careful investigation of the materials which are available in order to determine whether it will be cheaper in the end to use native materials or to bring others from a distance, even tho the cost of construction be increased. Such expenses as these might properly be considered part of the cost of administration, but, if no separate provision has been made for them, it is far better to draw upon the funds provided for the improvement, whether they be raised by budgetary appropriation or by bond issues or even by assessment for benefit, than to dispense with the preliminary investigations. Without such preliminary work, errors in judgment in the selection of the highways to be improved or in the choice of materials to be used and failure to correct defects in grade and alignment are quite sure to result in an unwise use of some of the funds and in failure to secure the best system of roads which is possible. In the case of a city street system, the preliminary work will be more extensive and will consume far more time and involve much greater expense. The need of topographical surveys, of a careful study of the transportation needs of the future streets, and the main drainage system, of a rational plan not only for the principal and secondary business or traffic streets but also for those which are to be devoted to residential purposes has been emphasized in several of the Articles in Sect. 7. The expense of this work is usually considered as properly chargeable to general administration but in some cities it has been met by the issue of long-term bonds for the reason that it is considered work of a permanent character which will last as long as the city itself. In large cities where there are subdivisions that can be separately taxed, there is no good reason why this expense should not be imposed upon the territory covered by the plan and assessed directly upon the real estate within its boundaries. What was previously acreage property, unavailable for urban development, at once becomes capable of subdivision into city lots fronting upon officially recognized streets, and there is no single step in its development, not even the physical construction of the streets, which will be of more direct benefit in that the property at once becomes marketable as city lots.

Titles and Surveys. When it is necessary to acquire title by condemnation proceedings to the land within street lines, further and more detailed surveys become necessary in order to determine the precise area to be

taken from each owner and the exact location of buildings which may be taken or damaged. As the cost of such acquisition is commonly assessed upon an area of benefit, the expense of such surveys and maps may be, and frequently is, included in the costs of the proceedings, but it sometimes happens that expensive surveys are required to locate certain lines, while information so obtained will be required in connection with similar proceedings relating to other parts of the same street or to adjacent streets. In such cases it is obviously unfair to impose this special expense upon the property which will be affected only by the particular street. Such work is properly chargeable to general taxation or to the same account from which the cost of the general plan was paid. Finally, there will be the surveys needed for the preparation of the actual contract plans and the cost of engineering and inspection during construction. These are nearly always charged to the fund from which the cost of the actual work is met, whether it is to be paid by the city at large and raised by any of the methods already referred to, or whether it is to be assessed upon the property benefited.

13. Acquisition of Titles

Valuation of Land for Highways. The existing roads in rural districts and the oldest streets in cities, which were once rural highways, have in most cases been created by traffic; they were not laid out in accordance with any plan tho the way for them was often cleared thru forests. Public right in them has been established by user and not as the result of any legal proceedings, and that right is generally an easement for highway purposes and is seldom a fee title. As new highways are acquired or when the old highways are widened or straightened the property is likely to be purchased, in which case a fee title is usually acquired. The state, town or city often exercises its right of eminent domain and condemns the land required thru a commission appointed by the court. Such procedure is necessary in case any part of the cost is to be assessed, as prices fixed by private agreement are likely to be questioned unless the owners who are to receive the awards and those who are to pay the bill have their day in court with an opportunity to make objections. These proceedings are cumbersome and expensive, and the unreasonable time consumed and the enormous costs are frequently the cause of much complaint and often of scandal. Extravagant claims are made as to the value of the land taken, full value for the area within the street lines being insisted upon. It is difficult to understand the mental process by which members of condemnation commissions arrive at their conclusions as to values. When a street plan has been officially adopted and the property has been sold the title is generally given to the center of the street. If the street is 60 ft wide and the abutting lots are laid out to have a depth of 100 ft, the title of the owner covers a total depth of 130 ft, half of which is within the lines of the street. This total area, however, is little more than acreage property and has no value as city lots until the paper street shall have been converted into an actual highway affording access to the lots. To claim city-lot values for the 30-ft strip without which the remainder is not susceptible of use seems absurd, and yet such claims are generally made and too frequently allowed. When the property which is left is not of such size or shape that it can be developed as building plots substantial compensation is equitable and proper, but the average owner of property which is to be condemned is insistent upon large awards for the taking of that

which is of no use to him until it is a public street, and he seems to have no difficulty in securing expert testimony to support his claims.

Buildings within Street Lines. In many instances buildings are erected wholly or partly within the lines of streets for the express purpose of securing large awards for damages after which the buildings or the portions of them which are taken are sold at public auction for a nominal consideration and are usually bought back by the original owner. This practice has been called HOUSE PLANTING, and there are authentic records of cases where, after securing large awards for such buildings and purchasing them back again for a few dollars, they have been deliberately moved to another site held by the same owner and wholly or partly within the lines of an unopened street and the same procedure is repeated. If the building is sufficiently substantial to survive several such moves, a very handsome return can be realized on the original investment. The most effective way to deal with the question of extravagant claims for property taken for street purposes is to assess directly back upon the abutting land the entire cost of the proceedings, in which case the claimants may have the satisfaction of paying their own awards, but this would not remedy the injustice imposed upon other owners as a result of house planting. It is obvious that in case there are not buildings within the street lines it is to the interest of the owners to cede voluntarily the land required for the street without compensation and save thereby the expenses of the proceedings which, when the cost of surveys, the making of the damage maps, and the fees and expenses of the condemnation commission are included, are considerably greater than the aggregate of the awards. In some states an attempt has been made to deal with the evil of the erection of buildings within street lines by the enactment of laws declaring that, after the proper city authorities shall have adopted an official plan showing streets and parks and property which may be taken for any other public purpose, any owner who erects a building within the limits of the land to be taken does so at his own risk and is not entitled to compensation therefor. Such a statute exists in the State of Pennsylvania and, while the constitutionality of such a law may be open to question, it appears to be so obviously in the public interest that it has not been successfully attacked in the Pennsylvania courts. It is true that such a policy may involve grave injustice if the taking of property so preempted is unnecessarily delayed. Any owner of land should have the right to make such use of it as may be proper and legal unless it shall have been taken from him by due process of law. When such owner shall have in good faith shown his intention so to use or improve his property, the city or the state should in justice act with reasonable promptness by taking that which they have declared their intention ultimately to take and pay a fair price for it.

Irregular Property Lines and Unusable Remnants. Where streets are so located with respect to property lines that irregular and unusable remnants will be left which cannot be profitably improved while in single ownership, or when street widenings result in leaving plots too shallow for suitable use, the damages are large and proper compensation must be made. A method of dealing with such cases, which has been strongly recommended of late, is the exercise of the right of excess condemnation when such right exists. This simply means that the state or the city in taking property required for a public use shall not be limited in its taking to the precise lines required in order to carry out the improvement, but that it may take the whole of parcels which may be so mutilated as to in-

volve substantial damage. After the improvement has been carried out the area not needed can be resold at the advanced price which will result from the improvement which has been made. This is really the taking of a part of the unearned increment or the increase in value caused by something which the public has done. It will, of course, require an increase in the capital investment and the power, if granted, should be conservatively used and land speculation for profit should be discouraged. This method has one great practical advantage in that remnants which could not be used in separate ownership, and which, when unimproved, would give the street a ragged and shabby appearance, may, when combined in a single ownership and with the possible addition of enough land to give suitable sites for buildings, become very valuable.

German Method. A method of dealing with the problem presented by very irregular property lines which will not fit a rational street system has been adopted by German cities thru the enactment of a law commonly known as the LEX ADICKES. This statute authorizes the city to take all of these irregular parcels, to lay out a suitable street system including such open spaces as are deemed necessary, and to divide the portion which remains among the original owners in proportion to their former holdings. While the area of each owner may be reduced 25% or more, depending upon the land taken for streets and open spaces, each parcel will be so located with respect to the streets as to be available for suitable development.

14. Grading, Curbing and Sidewalks

Grading New Highways. In creating a system of rural highways the surface improvement and such grading, regrading, straightening and draining as are needed are likely to be carried out at the same time and frequently under a single contract. In the case of a city street where there has been no existing highway, the first step is usually the grading, curbing and laying of sidewalks, while the pavement is commonly deferred until the abutting property is at least partially developed. This will not only allow time for the installation of the ordinary subsurface structures and the settlement of the trenches in which they are placed, but will prevent the mutilation of the new pavement by frequent openings for the ordinary surface connections, and it will also allow the property owners to meet the expense of the completed street in several payments. In cases where the grading is heavy and the cost of the improvement other than pavement is large in comparison with the value of the property, it is often desirable to carry out that part of the work progressively, the street being graded for only a portion of its total width or even to a temporary grade which will furnish a passable road and permit such development of the abutting property as is practicable before the final grade is physically complied with. If such a policy be adopted it is necessary to have a clear understanding that the grade is temporary and not final, and that such buildings as may be erected shall conform with the ultimate grade as officially adopted and that, if they are located with respect to the temporary surface, they will not be entitled to damages when the grading is completed.

Widening and Regrading Established Highways. Streets are frequently laid out to include old highways in use at a lesser width and lying wholly within their lines. The grades of such highways will have been established by user altho they may be entirely unsuited to either the traffic or the drainage of city streets. When the time for grading comes, serious damage will be imposed upon the buildings which may have been erected accord-

ing to the user grades, and such damage must be paid. While easy gradients are necessary on important traffic arteries, instances will be found in most cities where uniform grades have been established and physically carried out on local streets quite well built up, with the result that the houses are left some feet and often a full story below the new surface, while the damage might have been greatly lessened by the adoption of a modified grade which would have served the needs of the particular street. Such a grade may not conform with the ideas of the highway engineer but there are times when economic considerations should be controlling, provided always that a saving in the first cost of construction will not entail a greater subsequent expense or result in conditions prejudicial to the health, convenience or general welfare of the entire locality.

Curbing and Sidewalks. The curbing and sidewalks are usually laid at the expense of the abutting owners; in some cities their repair and renewal are also chargeable against the lot owners, while in others the burden is assumed by the city at large. In the latter case it is obviously in the interest of the owners to lay the cheapest material permitted, while the interest of the public requires that they be made as substantial and durable as possible within reasonable limits of cost. Aside from expense of renewals, where they are imposed upon the city, the public safety and convenience require that such renewals shall not be necessary at frequent intervals. Sidewalks are usually laid by the property owners under special permits and presumably in accordance with standard specifications. In the majority of cases they are put down by speculative builders whose interest in them lasts only until they can sell the houses. While cement walks can be laid far more cheaply than stone flagging, the builder is often disposed to make them even cheaper than is consistent with good workmanship. The cost of the house to the purchaser would be inappreciably affected by the difference between the best and the poorest work of this kind, and it is the duty of the responsible city officers to protect the investor as well as the city from the danger of accident resulting from defective walks and from the cost of replacing them with those that are suitable.

15. Pavements

Original Pavement. The cost of the original or first pavement is generally assessed upon the abutting property. In exceptionally wide streets this would involve so heavy a burden that a portion of the expense is usually placed upon a larger tributary area or is even assumed by the city. Very wide streets with several roadways are often treated as parkways and in such cases one of the roadways, which is designed to accommodate restricted or relatively high-speed traffic, is often paved at general expense. In streets having a width of 80 or 100 ft it is quite likely that there will be surface-railway tracks, and the traction company is usually required to lay and maintain at its own expense the pavement between its tracks and rails and for several feet outside of the outer rails. This will reduce the expense to the abutting owners so that it will be no greater and in some cases will be even less than that of the paving of an ordinary residential street. In some cities the railway companies are required to pay a certain annual sum per mile of single track in lieu of their paving obligation, the city assuming the entire expense of the maintenance of the pavement. Responsibility for the upkeep of pavement is, however, an incentive to substantial track construction which will materially reduce the cost of surface repairs.

Selection of Type of Pavement. Owners of property who are required to pay for the first pavement are disposed to argue that if they are to pay the bills they should have the right to determine the character of the pavement, and if this right is conceded they naturally select the cheapest type which is permitted, especially where they can not be called upon to pay for repaving. This not only involves greater expense to the city at large but it is impossible to carry out a consistent general plan of street paving. A change in the kind of pavement every few blocks is a serious handicap to travel, especially on lines of thru or continuous traffic. While the property owner who is to be assessed is not disposed to concur in this statement, the character of the pavement to be laid on each street should be determined by one who possesses expert knowledge of the kind of surface best adapted to the grades, the probable traffic and the general character of the development of the abutting property. It should not be necessary to wait until the first pavement is worn out and another is to be laid at public expense before a comprehensive paving plan may be realized. There is need of a paving program which shall be consistently carried out regardless of how the cost is to be met, regardless of the whims or projects of the abutting owners, and regardless of the missionary work of promoters of a particular kind of pavement who may have secured signatures to petitions which appear to indicate a decided preference for the type of roadway surface in which they are interested.

Pavement Renewals. While the cost of the renewal of the pavement is usually paid out of general city funds, the expense of maintenance and repairs is always so paid. Public opinion will no longer tolerate the neglect of pavements until they are so worn that travel over them becomes positively dangerous and an entire repaving is the only remedy. When repairs are made as needed and records are properly kept, the annual cost of maintenance is readily ascertained. The time for complete repaving is therefore easily determined and is when the maintenance expense becomes equal to or greater than the interest and sinking fund charges on the cost of a new surface plus the average annual expense of maintaining the new pavement during its life, assuming that the funds required are borrowed for a term of years correspondnig with the estimated life of the pavement which is to be laid. If the loan is for a longer period there may be an apparent reduction in the annual expense of the new pavement which might be held to justify an early replacing when the cost of repairing the old pavement equals or exceeds this sum, but there will, in the case of a long-term loan, be an overlapping of the financing periods which will vitiate such conclusions. The folly of the long-term loan has been so frequently pointed out in the preceding Articles that it will be assumed that it will not be resorted to.

16. Street Widenings

The Widening of Existing Streets constitutes a special and exceedingly difficult problem and the financing of such projects involves both the cost of the acquisition of additional property, the damages incurred by the destruction of buildings, and the physical improvement of the widened street. The cost of acquiring the land for street widenings, including damage to buildings, is commonly made a general city charge, altho in some cases a small portion of the expense is assessed upon an area of benefit. The fact that a widening is necessary is a clear indication that the street has assumed more than local importance, but it may also be assumed that its local importance will be increased to a certain degree by the

widening and, as already pointed out, if there is a local benefit, that benefit should be recognized by some local assessment. The general principles hereafter outlined in Arts. 17 and 18, which should govern the distribution of the expense of acquiring title to a new street, can with justice be applied to the widening of an existing street, with the understanding, however, that the share of the expense imposed upon the restricted local area of benefit, usually the frontage, should relate to the land damage only, while the building damage should be included in the share assumed by the larger district or the city. If, for instance, a street 50 ft in width is to be widened to 80 ft, the frontage assessment should be limited to that portion of the cost of acquiring the 30 ft of additional land represented by the 10 ft necessary to give the street a width of 60 ft and one-fourth of the width in excess of 60 ft, which in this case would be a total of 15 ft or 50% of the land damage, the remaining 50% together with the building damage being placed upon the larger district or districts of benefit. In case a street 50 ft in width were to be widened to 100 ft, the portion of the expense for additional land which should be placed upon the first area of benefit would, under the same theory, correspond with 20 of the 50 ft to be acquired or 40% of the land damage, the building damage, as before, being included in the assessment to be placed upon the larger area of benefit.

Old Irregular Roads Included Within Street Lines. It frequently will happen that in the first platting of a street system an existing highway along which there has been a certain amount of irregular building is to be included in a new highway of greater width. While this would not constitute a widening in the sense above referred to, it is a widening so far as its effect upon the adjacent property is concerned, and in such cases an equitable distribution of the expense will be as follows: For the area within the lines of the old highway it is probable that no awards will be made in view of the public easement. If the old highway was 40 ft wide and the new one is to be 80 ft in width, a separate estimate should be made of the value of the undedicated land to be acquired and another estimate of the building damage. If it were found that the building damage were twice as much as the land damage, this might be considered as equivalent to the acquisition of 80 ft of land in addition to the 40 ft which are to be acquired to give the existing highway a width of 80 ft. There would then be an equated width of 120 ft, and the rule proposed in Art. 18, if applied to this width of 120 ft, would result in placing 62.5% of the total cost, including building damage, upon the restricted local area and the remainder upon the larger district. If this equated width, due to estimated building damage, were added to the total width of the street as laid out, instead of the width of the undedicated portion, the total equated width would be 160 ft, in which case, limiting the total width to be assessed to 80 ft, the proportion of the expense to be locally assessed would be 50%. This method of distributing the cost in such cases is believed to be worthy of serious consideration.

ASSESSMENTS FOR BENEFIT

17. The Theory of Assessments

Local and General Benefit. As intimated in the preceding Articles, the demands upon the resources of the state, and more particularly of the modern city, are so great that in addition to the general taxing power resort must often be had to assessments for benefit whenever possible in order

to meet the cost of improvements where the benefit can properly be considered local. But the theory of assessment for benefit is not that it is something that can be employed when the public funds are required for other purposes where local benefit is not clearly established, but it is founded upon the general principle that where there is local benefit there should always be local assessment. There can be no improvement which has been intelligently planned and executed which will not result in some local benefit and it follows that there should always be some local assessment. No improvement, however small or however large, will be of equal benefit to the entire city, and to distribute the burden of paying for it over the whole city according to taxable values is unfair in that it is not placed according to benefit. The owners of property in the immediate vicinity are frequently enriched at the expense of those whose holdings are entirely outside the district directly affected.

Special Assessment for Local Benefit. The practice of assessing the cost of street or local improvements is probably more general in the United States than in other countries and it is accepted as an equitable and rational plan. In a paper read before the Municipal Engineers of the City of New York in May, 1914, by William C. Ormond, the President of the Board of Assessors, there is a review of the manner in which this policy has been developed, first to a limited extent in England and later and more fully in the United States. One of the earliest statutes which specifically recognized the theory of assessment according to benefit was enacted by the State Legislature of New York in 1787. The courts have repeatedly passed upon the equity and reasonableness of this manner of financing local improvements. A Kansas judge in sustaining the legality of a special assessment said: " There is a justice in this arrangement which commends itself to any right-thinking man, but the injustice of assessing property all over a city for the improvement of a single street must be apparent at a glance." A Mississippi court, while cautioning against the improper use of the power to assess, emphasized the justice of the plan in these words: " I concede that the system of local assessment is liable to abuse, for which reason courts should scrutinize its application with care and also see that an equitable share of the burden should be borne by the public, but it will be readily foreseen that if the whole local charge for local improvements is to be borne by the city treasury, grievous abuses might be practiced upon the inhabitants generally to subserve the local interests of designing men holding property in a particular neighborhood." While the subject under immediate consideration is the financing of highway improvements, the principle of assessment for benefit is capable of a much broader application. While there are certain great projects that are commonly deemed of general interest, there are few which do not involve some special benefit to a particular locality. If a new park is to be created the property in its immediate vicinity will acquire a certain fixed character and its value will be substantially increased. If a new and important public building is to be erected there will be much interest in the selection of the site and, as soon as it is determined, it will have a marked influence upon the property in the neighborhood, and it would not be difficult to give instances where, before the building was completed, the value of the surrounding property has at least doubled, especially if the building is surrounded by considerable open space. If the city were, as some of our great cities now do, to construct a new rapid-transit line bringing hitherto vacant lots within easy reach of its business center, or

if it were to provide a new waterway permitting docks and basins to be created in hitherto inaccessible swamps, the effect upon this suburban land and these useless swamps can be readily foreseen. If the property in the neighborhood of the new park, the new public building, the new transit line or the new waterway is to be increased in value by some act of the city, and if the owners of this property are to be enriched by this act, it is fair and just that these owners should contribute more per unit of assessed value toward the cost of the improvement which is to enrich them than do the owners of other property more slightly, if at all, affected.

18. General and Special Benefits

Local Benefit. In the case of streets that serve a strictly local purpose the benefit may be considered to be entirely local and the entire expense can properly be assessed directly upon the abutting property, but there will be many cases where the benefit will be more than local and will extend to a considerable distance beyond the immediate frontage, while it may even be of substantial service to the entire city or even the metropolitan district. Nor does the relative amount of local or general benefit in all cases depend upon the width of the street which is to be acquired and improved or upon the cost of the improvement. A street 50 ft wide may be of more general use than one 100 ft wide which has been planned to give a distinctive character to the abutting property or to that within a limited district. An improvement costing $100 000 in one part of the city may be more distinctly local in its benefit than one costing $10 000 in another section.

General and Local Benefits Affected by Street Widths. While no definite rule can be adopted to govern the distribution of assessments representing general benefit over the district or the geographical units to be assessed, it should be possible to prescribe a method of determining the amount and extent of local benefit, particularly in the case of new streets and boulevards. Let us assume that 60 ft is the maximum width required for a local street; then the entire cost of acquiring and improving all streets 60 ft or less in width may properly be placed upon the property within a half block on either side of the street. In the case of wider streets that proportion of the cost represented by the ratio which 60 ft plus 25% of the excess over 60 ft bears to the width of the street would probably be an equitable proportion to assess upon the local district. Up to a certain limit, property fronting a wide street is more valuable, and it would be manifestly unfair to adopt a rule which would result in making the cost of acquiring a street 70 or 80 ft wide no greater or possibly less than would have been the cost of a street 60 ft wide. On the other hand, after a street reaches certain proportions, additional width will not involve additional benefit. It may be assumed that a share of the expense which would be equivalent to paying for a street 80 ft wide should represent the limit of local assessment. This limit would be reached under the rule proposed when the street becomes 140 ft wide. The percentages of cost which would be locally assessed would therefore be as follows for various street widths: 60 ft, 100%; 70 ft, 89.3%; 80 ft, 81.25%; 90 ft, 75%; 100 ft, 70%; 120 ft, 62.5%; 150 ft, 53.3%; 200 ft, 40%. This plan of distributing the expense is shown diagramatically in Fig. 1, which also indicates the proportion of the cost which might equitably be placed upon a secondary area of benefit, or upon the entire city in the case of very wide streets. It has been assumed that, beginning when the street exceeds 60 ft in width, the

amount assessed upon the secondary area of benefit will gradually increase with the street width until the latter becomes 140 ft, at and after which the frontage assessment and that on the secondary area will remain respectively at the proportions corresponding with 80 and 20 ft, the remainder of the expense being placed upon the city at large.

Tuttle Plan of Distribution of Assessment. In any case, no rule should be adopted until it has been carefully tested and it has been demonstrated that the assessments levied in accordance with it will constantly decrease with the distance from the improvement. This decrease should not be directly in proportion to the distance but in a geometrical ratio. A curve to determine the distribution of assessment after the limits of the district have been decided has been proposed by Arthur S. Tuttle, Deputy Chief Engineer of the Board of Estimate and Apportionment of the City of New York, in accordance with which about 32.5% of the assessment would be placed upon the first 10% of the distance to the outer limit of the area of benefit, 55% upon the first 25% of the distance, and 80% upon the district extending half way to the boundary of the assessment area (see Fig. 2). The diagram, illustrated in Fig. 2, could also be used to determine the boundary of the district of assessment if it were decided to place a certain percentage of the expense upon the immediate frontage and to distribute the remaining cost over the rest of the district in properly graduated proportions.

Fig. 1. Diagram Showing Proposed Distribution of the Cost of Acquiring Streets of Different Widths Between the Abutting Property and Larger Areas of Benefit

19. Installment Assessments

Payment by Installments. The privilege of paying by installments is given by some cities and this lightens materially the burden of the property owner. Such a policy involves a greater capital investment on the part of the city as there is a much longer period between the time of the first outlay and the return by the payment of the assessments. In small cities it was formerly customary to pay the contractor for street improvements in warrants issued against the owners of the property chargeable with the cost of the work, such warrants being a lien upon the real estate and the contractor being obliged to enforce payment by legal action if he could not otherwise collect the assessments. While these warrants carried interest, the delay and in some cases the legal steps required to make the collections resulted in substantially higher bids, altho the city's financial obligations were lightened. This method has been quite generally abandoned. The city pays for the work as it is done and it is customary to include in the assessment interest on all payments from the date of the disbursement to the time of the confirmation of the assessment

roll or to such a date subsequent thereto as will allow time for proper notice that the amount levied against each piece of property is due. After a reasonable time in which to make the payments the assessments become arrears and a higher rate of interest is charged until they are paid, and in many cities no payments are accepted except for the full amount of the assessment.

Benefits of Installment Plan. When the amount of the assessment is a substantial proportion of the actual value of the property it is exceedingly difficult for some of the owners to discharge the obligation in a single payment, and in order to lighten the burden the right to pay in five or ten annual installments is sometimes granted when the amount of the assessment exceeds a certain percentage of the value of the property as assessed for purposes of taxation, this percentage varying from 10% to as low as 3%. The value considered should, of course, be that of the land exclusive of buildings in order that property owners who have added to taxable values by the erection of buildings should not be discriminated against. Interest on installments is usually charged at the rate of 5 or 6% from the time of the levying of the assessment until they are paid, such interest on all unpaid installments being due and payable with each installment.

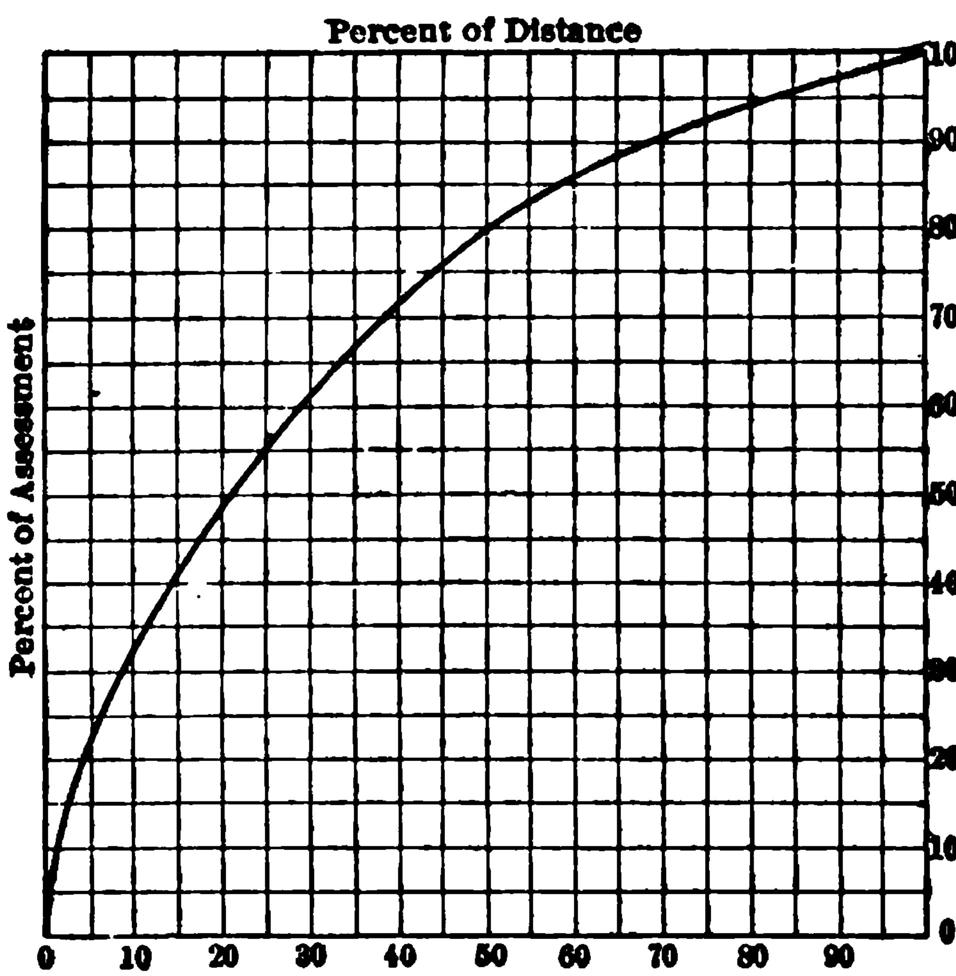

Fig. 2. Diagram Showing a Method of Grading Assessments for Benefit According to the Distance from the Street to be Acquired

European Practice. In European cities the rate of interest which is charged is often very small, in some cases as low as 2%, but in some of these cities, especially in Germany, there are large amounts of capital available for this purpose, the result, often, of real estate operations in which the cities may engage or the result of profits from the operation of the public utilities which are generally owned and operated by the municipalities. This does not mean that in German cities it is easier for the owner of a modest home to secure and pay for his street improvements, as there are other regulations which make it very difficult, if not impossible, for him to do so. It is a common practice, for instance, to refuse to permit the owner of a plot to erect a building until the street upon which it fronts shall have been entirely improved with curbing and pavement connecting with another street or a part of the same street which has already been so improved. The result of this policy is that the built-up parts of the

city grow solidly outward with no vacant spaces and no unimproved streets intervening between the older and the newer portions. Another result is that street improvements and building operations are generally undertaken only by corporations, such as banks and realty companies, having abundant capital. The practice of allowing assessments to be paid in installments appears, therefore, to prevail to the greatest extent and on the most liberal terms under conditions where that privilege is not most needed, or, at least, where it cannot be availed of by those who need it most.

20. Deferred Benefits

Potential and Immediate Benefits from Improvements. Benefit results from street improvements in all cases, but in many instances it is a potential rather than an immediate benefit. If the owner of the property is prepared to improve his holdings at once in order that they will bring him some return the benefit is realized. If he has not the means to develop it, his capital investment is increased by the amount of the assessment but will bring him no immediate return. If the property is already built upon the benefit is immediate and is at once reflected in an increased rental value, or more livable conditions or better business conditions if he occupies it himself. In the great majority of cases the abutting property is unimproved and unproductive at the time the street improvement is made and the improvement is asked for in order that it may become productive or marketable. But a long delay often ensues before the owners, or at least some of them, are able to take advantage of the bettered conditions resulting from the grading or paving of the street.

German Method. To meet such conditions some cities recognize the fact that the benefit is deferred and, while the city may advance the money, the assessment is not payable and does not become a lien upon the property until it is improved in such a manner that the benefit ceases to be merely potential and becomes actual, a low rate of interest being charged for the period between the initial expenditure and the imposition of the assessment. This also is distinctively a German policy. Its great advantages to the property owner are obvious but it also greatly increases the amount of the municipal funds which are diverted from other purposes. The advantages, as in the case of installment assessments and under the restrictions noted in the preceding article, are enjoyed by the corporations which can undertake improvements on a large scale, and seldom extend to the small individual property owner or purchaser unless the corporation making the development gives him the advantage of the generous treatment it has received. Under the system of governmental control and regulation which generally prevails in Continental Europe such a share in the advantages of the system are likely to be insured to him.

Unused Sources of Revenue. In the United States such methods of financing local improvements have not been attempted owing to the extensive demands which are made upon the resources of cities for other purposes. It is only lately that the cities have begun to avail themselves of sources of revenue other than those derived from the taxation of real estate. Franchises in perpetuity to use the public streets at, above or beneath the surface were formerly given away without substantial compensation. The Federal, State and Municipal Governments have but lately awakened to the necessity of conserving and developing their resources in such a manner as to derive an income from them. They have not been disposed to attempt to render service which it has been argued can be more efficiently and more

economically furnished by private corporations, and they are still reluctant to do so. The size of vehicles using the streets has increased until traffic is seriously obstructed and, while loads have increased until the pavements and their foundations are seriously damaged, no steps have been taken to derive a revenue by the imposition of a special tax upon vehicles of excessive size or upon excessive wheel loads. The widening of the roadways to accommodate larger vehicles and the replacing of pavements broken down by heavy loads involve large additional expenditures, while the cost of administration is constantly increasing and almost the entire burden falls upon real estate. Upon this same real estate must be imposed the cost of street improvements thru the medium of special assessments. The burden is a heavy one and some of the methods of relief which have been outlined in this and the preceding Article, while admittedly desirable, cannot be adopted until some other means are devised for providing revenues in addition to the taxation of real estate.

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SECTION 29

ORGANIZATION AND ADMINISTRATION OF HIGHWAY DEPARTMENTS

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ORGANIZATION

1. General Considerations Relative to Organizations

The Essential Prerequisites of an Efficient Highway Engineering Organization has not been given proper recognition in many localities in the United States. The fault lies partly with the engineer and not entirely with the politician, who frequently is blamed for this state of affairs. The average so-called organization politician of the leader type is in many cases a man who interests himself in public affairs for a financial return; he makes a business of politics and lives by it. It is natural that any public work not generally recognized by laymen to be distinctly engineering work would not be regarded as such by the politician, whose desire is to provide as many places as possible for his associate political workers, among whom few engineers are found. The responsibility for this state of affairs, therefore, rests in a measure with the engineer, since the engineering profession as a whole has regarded the highway problem too lightly and has not been sufficiently jealous of the infringement upon its rights, namely, to supervise all work, public or private, that is of an engineering nature. The doctors

and lawyers have to build up safeguards to protect what they consider their prerogatives. You never find an engineer supervising or conducting work coming under the jurisdiction of either one of these professions, but there are innumerable cases of lawyers and business men placed at the head of highway departments, the excuse being that they are executives. Nevertheless, this is engineering work, and while one of the principal requisites for such a position is executive ability, engineering knowledge is equally important, and the real qualification essential for the directing head to successfully conduct such a department is engineering executive ability, not executive ability engineered by a business man or a lawyer, such as we have been having in many of our state, municipal, county and town highway departments.

Responsibility of the Highway Engineer. Business concerns must advertise their goods, not only for the purpose of encouraging sales but for the protection of the public, as well as for self-protection; they must call attention to any imitations that will not answer the purpose or bring about the desired results. Likewise, it is the duty of the engineering profession to educate the public to get a dollar's worth for a dollar of expenditure, whether it relates to public or private work, so long as it is engineering work, by employing competent engineers to supervise highway and other engineering work. This means engineers to plan, organize, and operate all highway departments. In other words, a proper highway engineering organization does not mean engineers working under the direction of a lawyer or business man commissioner, but an engineering organization from top to bottom, with an engineer heading the organization, no matter what the title may be. This principle is an important one and should be ever before the engineer. He should be brought to consider seriously the prerogatives and functions rightfully belonging to members of his profession, organization work, executive ability, business management. The outlines of highway engineering organizations that will follow are based on the principle that there will be a single executive in charge who shall be a highway engineer.

2. Fundamental Principles Underlying Highway Organizations

A Definition of Organization, with particular reference to highway work, follows: The combination of correlated integral parts into a whole to systematize and simplify the operation, and bring about a maximum of efficiency in the service rendered with a minimum of friction. Using this definition as a guide and common sense principles in its application to organization or reorganization work, the ground work will embody the fundamental principles of organization. The carrying out of these principles involves a detailed study of the functions coming under the jurisdiction of the organization and their relation to one another. The combination of the correlated integral parts into a whole should constitute a logical arrangement of the principal functions of the organization and not an arrangement to suit the personnel, unless it is only temporary and necessitated thru force of circumstances. This point is brought out because there are so many instances where certain functions of an organization are grouped for the purpose of putting them under the jurisdiction of an individual who is qualified to handle the work. This is contrary to the fundamental principle of organization, and is the poorest kind of logic. The organization should be planned and the work systematized in such a manner that it will not be dependent upon any individual. The old idea of carrying your organization in your hat is exploded and generally considered to be the greatest enemy of sound business engineering

management for all classes of public works. Unfortunately, however, many departments are still run along such lines, the officials forgetting that it is not their business but the public's business, and that their occupancy of office is only temporary, while the business must go on forever, which makes it perfectly obvious that the organization should be planned in such a manner that it will not be dependent upon them. This does not mean, of course, that a poor selection of division heads will not result in the machinery running down or becoming somewhat rusty. In order that the organization may operate on an efficient basis, it must be properly guided, and right ' ere attention is called to the fact that the human element is a most important one. To control and operate an organization in an efficient and economical manner, it is not only necessary that those in charge of the different functions know how the work should be done, but they must have the good will of their men. It is only in this way that a maximum of efficiency can be brought about in the service rendered with a minimum of friction.

Controlling Factors of Highway Engineering Organizations. The controlling factors in organizing any highway engineering department come under the headings of preliminary studies and organization of an operating department, and include under preliminary studies, (1) scope and character of work, (2) area under control, (3) population and how apportioned; and under organization of an operating department, (1) planning of the organization, (2) selection of the personnel, (3) administrative control, (4) division of responsibility, (5) systematizing the work. The general principles involved in these headings apply to any highway engineering organization, and in order that a logical solution of the problem may be presented, each one of these controlling factors will now be considered.

3. Scope and Character of Work of Organizations

All work relating to public property between the boundaries of highways should come under the jurisdiction of the highway department, whether it be a state, municipal, county or town department.

Municipal Highway Department. The work that should come directly under the control of such a department is as follows:

1. The design of all work pertaining to the highways, including parkways, park drives and small highway bridges.
2. All engineering work relative to lines, grades, inspection of construction, etc.
3. The construction and maintenance of all highways, including streets, roads, parkways, park drives, etc.
4. The control of subsurface structures and encroachments, including all underground conduits, pipe lines, service connections, vaults, steps, street signs, stands, etc.
5. Permits and licenses for vehicles of all kinds.
6. Street cleaning and snow removal.
7. Collection and disposal of ashes, rubbish and garbage.

State Highway Department. The state, while not having the variety of activities, may have as many or more subdivisions of the organization, due to the larger area under control. These activities may be as follows:

1. Planning of route layout and design of all work pertaining to the system of state roads, and county and township roads, including parkways, park drives and highway bridges under state aid.
2. The control of all engineering work relative to lines, grades, inspection of construction, etc.

3. The construction and maintenance of all highways, including those constructed or reconstructed under state aid.
4. The placing of subsurface structures and encroachments, on or under all roads under state control.
5. Permits and licenses for vehicles of all kinds.
6. Enforcement of traffic regulations.
7. Street cleaning, usually snow removal on roads under state control.

County and Township Highway Departments should have control of the same activities for highways under their control as outlined for state highway departments. State laws may, however, as in the case of traffic regulations, give jurisdiction over certain activities to a state department. In some cases, a township or even a county may have charge of one of the usual activities under the control of municipal departments, namely, the collection and disposal of ashes, rubbish and garbage.

4. Area Under Control of Organizations and Distribution of Population

Area under Control. It is obvious that in so far as it is possible all the work should be controlled and operated from one central office. This principle, however, in its narrow sense can only apply to situations where there is a small area under control, such as in a small city or township. As the area increases, the responsibility for carrying on the work must be delegated and while primarily under the control of the central office, the actual operations must be under the control of subdivisions of the organization. For example, in a state highway department, the construction and maintenance work will necessarily have to be carried on under a number of subdivisions of the department. The layout of the routes and planning of the work drawing of specifications, advertising the contracts, etc, however, should be carried on in the central office. Likewise, as the area increases the personal touch with the engineers and employees engaged in supervising the work becomes increasingly difficult and makes it more important to keep the organization machinery well greased so that the operations will run along smoothly, and not only will construction work be carried on to the best advantage, but the details of the maintenance will be given the attention they should receive.

The Population and How Apportioned, is one of the controlling factors in connection with the layout of the system of highways. The distribution of the mileage of highways thruout a system will materially affect the location and personnel of the division organizations.

5. Planning the Organization

It is only necessary to glance over the scope and character of the work coming under the jurisdiction of a large highway department to become convinced of the fact, that no matter how able the personnel may be, ease of operation and economy and efficiency in controlling the different branches of work will vary with the character of organization under which the department is operating. The ideal organization is the one under which it is possible to accomplish results in the most efficient and economical manner and along the lines of least resistance. The perfecting of such an organization is the real problem and grows in importance, depending upon the number of activities, volume of work, and area under control coming under the jurisdiction of the department. The fundamental principles in-

volved in the planning and operating of a successful organization are the same, whether it be a state, municipal, county or town highway department, tho the activities are of a somewhat different nature. The difficulties to be surmounted depend largely on whether the project consists of planning an organization for a new department or, which is more often the case, the reorganization of an existing department. The latter is the far more

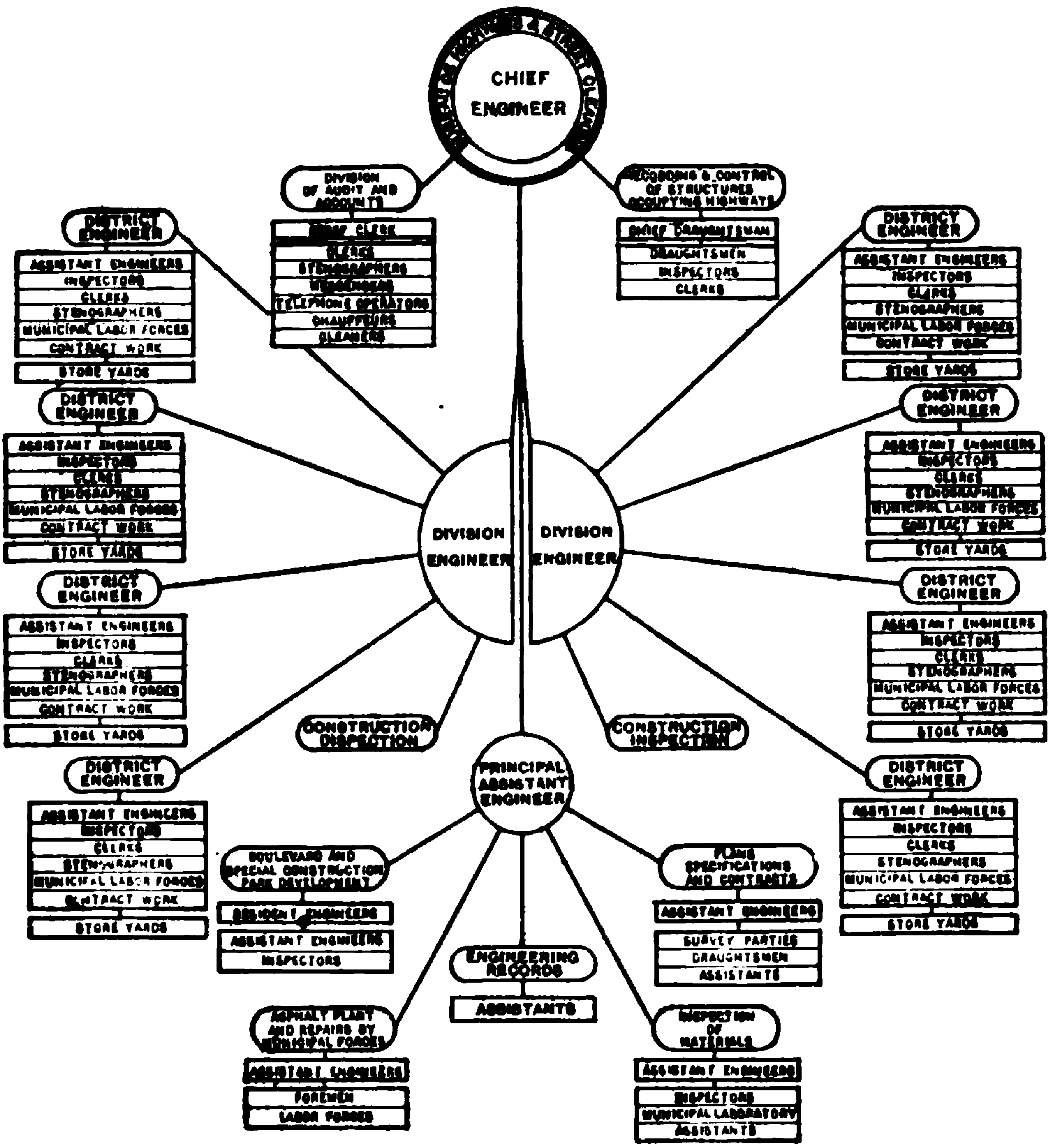


Fig. 1. Organization of a Modern Highway Department

intricate problem, and one that will be outlined with reference to a large municipal department in an endeavor to define some of the principles involved and the difficulties to be overcome.

After having completed the PRELIMINARY STUDIES, the next step is to proceed with the plan under which the department is to operate. This must be done with a view to the future, having in mind the passage of the necessary legislation to put the department on a thoro business basis, and still must be sufficiently elastic to cope with existing conditions, as most of the operations coming under the jurisdiction of a highway department

are of such a nature that they should not be put aside pending proposed legislation, or investigations with a view to a reorganization of the department. It is far better to turn the work out under what might not be an ideal organization, using the necessary safeguards to see that it is properly done, than to hold up the work, not only to the great inconvenience of the public but with a resultant financial loss thru interest charges on appropriations already made, and depreciation on existing plant, to say nothing of the loss due to carrying the overhead charges, and the deterioration of roads and pavements thru lack of maintenance. Reorganization to be constructive

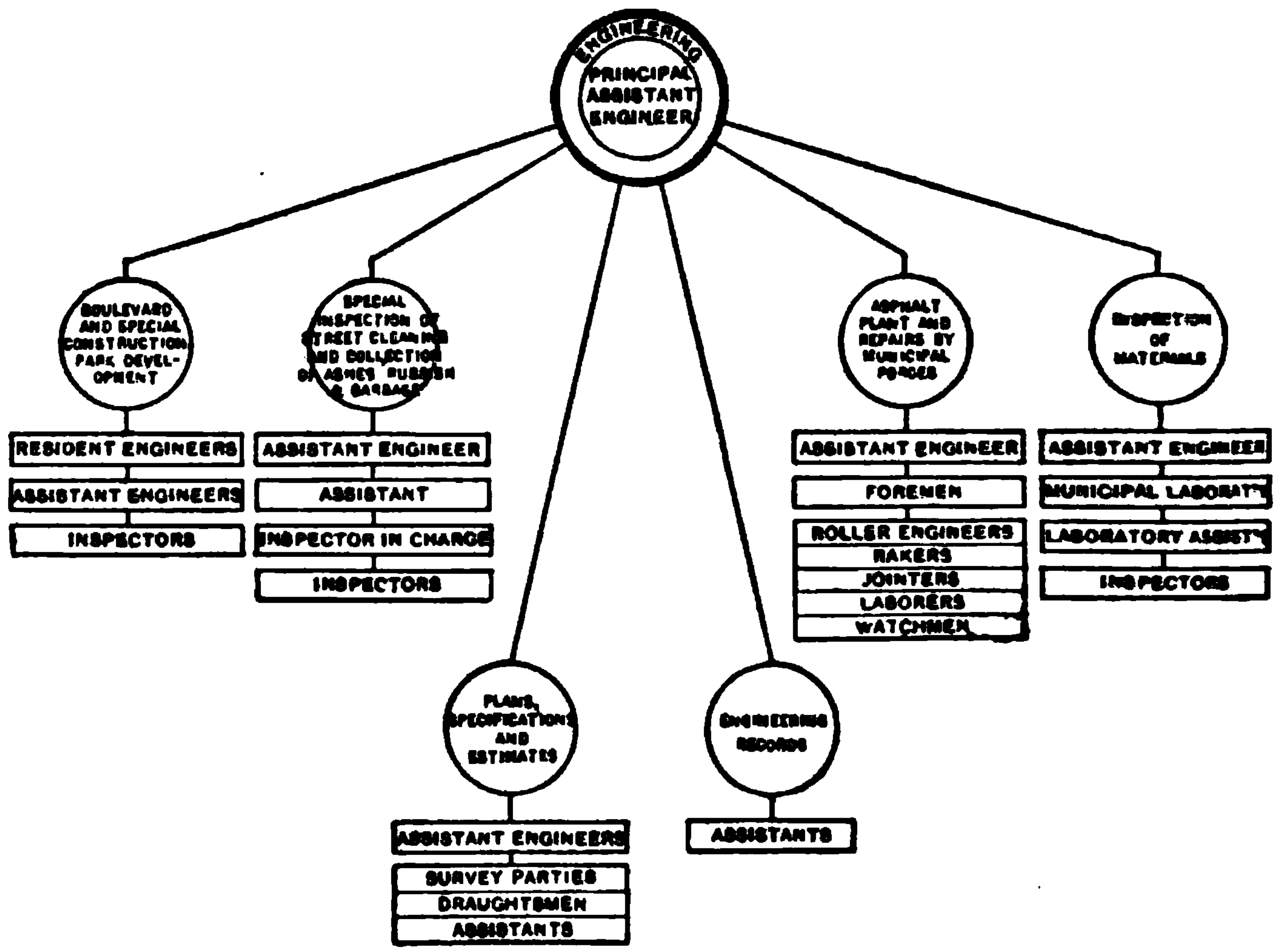


Fig. 2. Organization Chart of the Functions under the Jurisdiction of the Principal Assistant Engineer

must be brought about gradually. The primary consideration in the planning should be to centralize the control of the work, not only as relating to the head of the department, but this principle should be carried right down thru the organization. This means grouping the activities and combining them as far as is practicable, so that not only will the head of the department be familiar with all the activities, but the entire supervising force will be trained to direct all branches of the work. This will do away with shifting responsibility which is so often the case where the maintenance, construction and street cleaning work are under separate divisions, and will tend to make the organization a more stable and lasting one, as the entire force will be working as a unit, and being familiar with all branches of the work, each and every one will have an equal opportunity to advance.

For examples of organizations based on centralized control, see Figs. 1 to 5 inc. The organization chart of Fig. 1 is for a large highway municipal department; and charts, Figs. 2, 3 and 4, for the subdivisions of this same department, as will be seen by making a study of the chart for the general

organization. The organization shown in Fig. 5 has been recommended for a large state highway department, see (17). The fundamental principle set forth in these organization charts is to emphasize the importance of the principle of centralization of control and the delegation of responsibility to different subdivisions in the organization. These charts can be very readily worked into shape for use in any state, municipal, county or township department by making the necessary changes to suit the different character of work and titles of the subdivisions of these organizations.

Selection of Personnel. The personnel other than those of the clerical, stenographic, audit and accounts, and purchasing divisions, should be men of

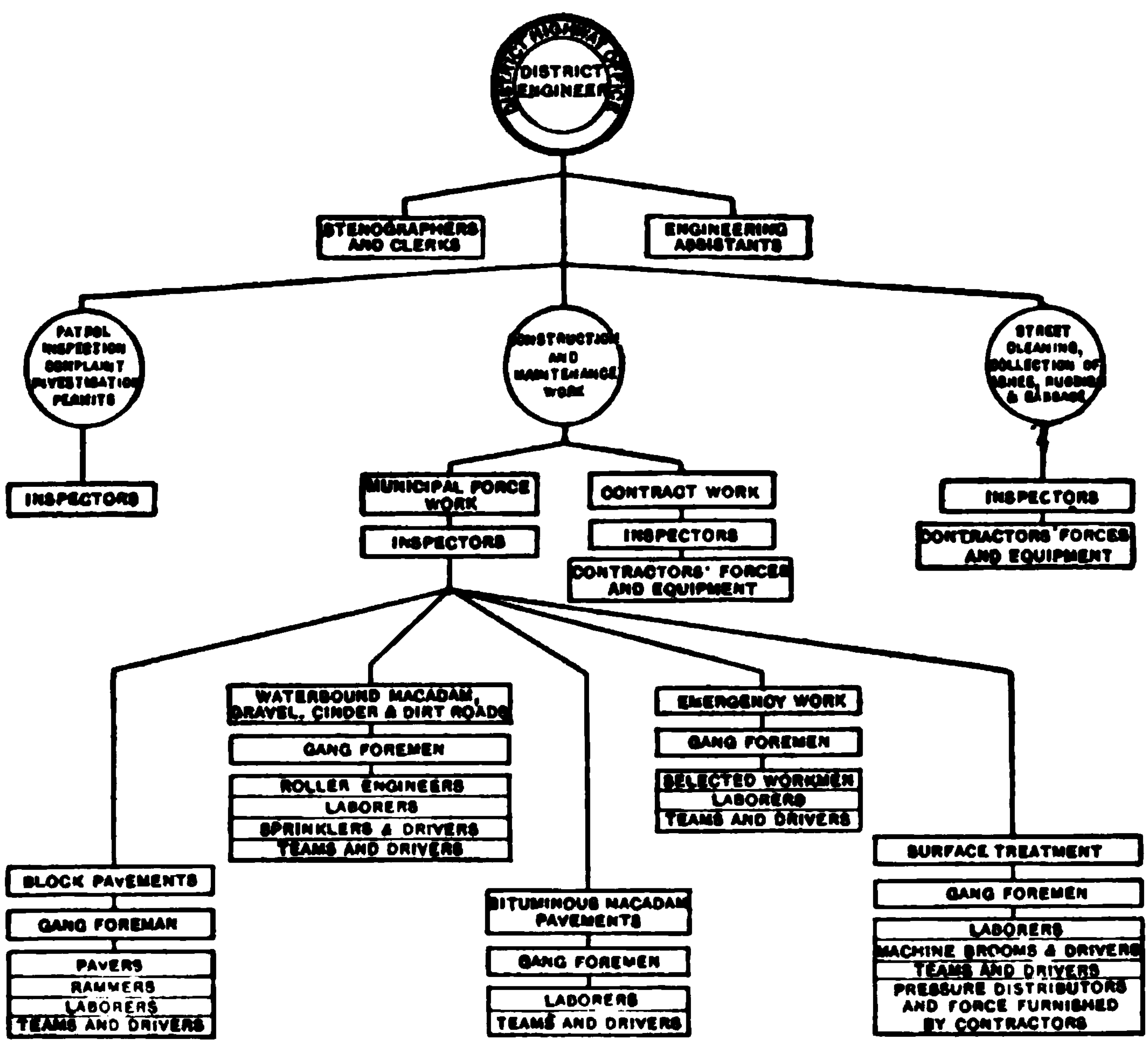


Fig. 8. Organization Chart of a District Highway Force

technical training and experienced in highway engineering, with the exception of the grade of inspector, where a man experienced in highway construction would be qualified. The entire force should be graded in such a manner that the organization will be well balanced. There should not be too many nor too few of the employees in the lower, medium or higher grades, but a proportionate number in each, depending upon the amount and character of work involved. The clerical, stenographic, audit and accounts, and purchasing divisions, as a general rule, remain constant all the year around, while the engineering force necessarily varies with the weather conditions or working season.

Inspectors. In most cases, the temporary inspection force should con-

sist of men who have had practical experience in highway construction, such as foremen, pavers, etc, or in some instances college graduates or students who make a practice of working during the summer months and who have had practical experience in highway work, as a green inspector will usually do more harm than good. The pay for these inspectors should range from about seventy-five to one hundred dollars per month. Ordinarily, during the working season, this force will constitute a large percentage of the entire organization, and it is obvious that those engaged in the inspection of construction work cannot as a general rule be carried during the winter months or when the work has shut down, as their services would not be required. There are, of course, cases where these men might be employed in some other class of work under the state, municipal, county or township government, and if such a thing can be arranged, it is very desirable, as

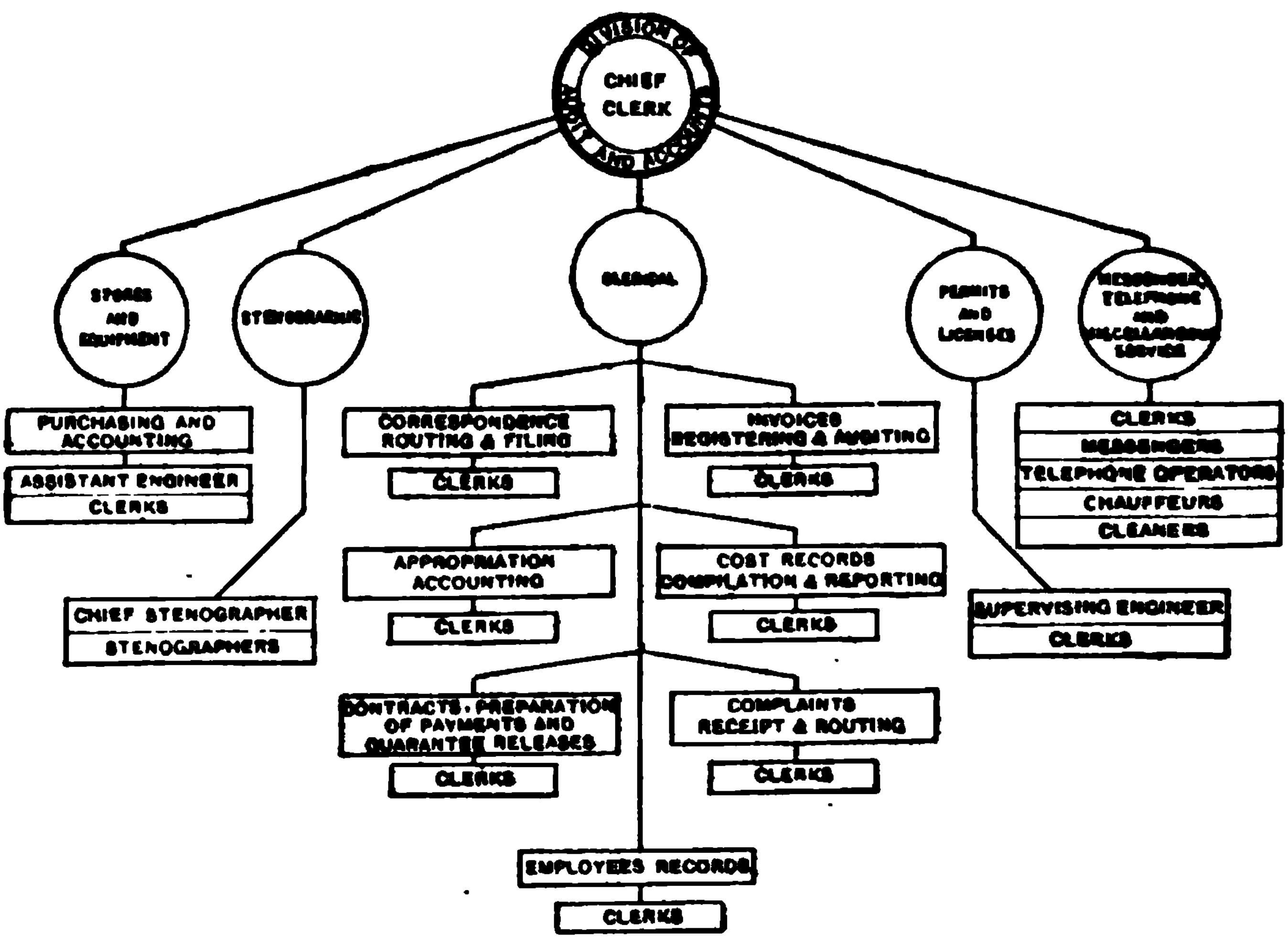


Fig. 4. Organization Chart for a Division of Audit and Accounts

the services rendered by persons regularly employed are superior to those of persons only temporarily engaged.

Effect of Civil Service Regulations. In large organizations the selection of the personnel is one of the most important factors, and, in many localities, is becoming one of the most difficult problems, due to the methods employed by some of the civil service commissions in determining the qualifications requisite for the selection of candidates for the higher positions where personality, broad experience in controlling work and good, sound business judgment should be the primary considerations. These qualifications are recognized to be essential for division heads in whom great responsibility is centered and on whom the success of the organization largely depends, and it is obvious that the selections in these cases should be left somewhat to the judgment of the head of the department, who is held responsible for the work, rather than to the judgment of a

civil service board or thru open competition in a technical examination. Civil service was intended to safeguard the interests of the public and to do away with the SPOILS SYSTEM but the principle of civil service should be construed in a sufficiently broad manner to permit heads of departments to command control of the work, and this can only be done thru a broad application of the civil service laws with regard to the selection of division heads in a large department. Considerable stress is laid on this point as the responsibility of the planning and success of the organization or reorganization in a highway or any other department, rests largely with the head of the department. It is, therefore, obvious that his judgment should

Fig. 5. State Highway Organization Recommended by Blanchard and Hubbard, Advisory Highway Board of N. Y. State Dept. of Efficiency and Economy (17)

carry some weight in the selection of his principal aides on whom he is dependent, as no matter how correct the planning may be to carry on and control the work, the ultimate success will depend largely upon the personality and judgment of these men.

The Qualifications Necessary to Make a Successful Division Head vary with the scope and character of work coming under the jurisdiction of the organization. Just because a man is a good highway engineer does not mean that he will be a success. Personality and business judgment carry just as much weight as engineering ability. The right type of man for such a position must not be lacking in imagination and should possess

the faculty of not only being a natural leader and commanding the respect of his subordinates, but he should also have their good will and this means that he must establish a sort of *esprit de corps* in the organization. A man who operates thru the good will of his subordinates accomplishes far more than the stern disciplinarian who lacks their good will and is feared by them. This is especially true in government, state or municipal work, where the civil service laws and other considerations minimize the authority of the department heads.

In Counties and Townships as a rule the situation is quite the reverse of that where the civil service is administered along narrow lines, and very often men who are entirely lacking in the proper qualifications are selected to control and supervise highway work, purely for political reasons. In some instances, the authorities believe they have the necessary qualifications because they knew something of the practical side of road building in the days before this work was revolutionized thru the advent of the automobile. This type of man usually adheres to the old methods and is too set in his ways to change. In these days every county and township should have the advice of highway engineers, and if this is universally done, many millions of dollars will be saved to the taxpayers. In every case an engineer should be in charge, and the responsibility for the selection of methods of construction and types of pavement should rest with him, and the local authorities should bow to his judgment in such matters; his assistants should also be engineers or men experienced in road construction. The selection of the personnel for counties and townships is relatively just as important as for a city or state, and as is the case in all matters pertaining to a highway engineering organization, the general principles enumerated here, with reference to the selection of the personnel, are applicable to state, municipality, county and township.

ADMINISTRATION

6. Administrative Control of Highway Work

The administrative control of a highway department is dependent upon a proper arrangement of the functions of the organization in their relation to one another, operating under a thoroly systematized procedure designed to bring about a maximum of economy and efficiency with a minimum of friction in conducting the work of the department. The administrative officers should act in an advisory capacity in connection with the work coming under the jurisdiction of the department and should show tact, initiative and judgment in the management of the organization and in dealing with the public, other departments and legislative bodies. This phase of the administrative control is what might be termed the business executive side of highway engineering and the same principles should govern this work as are in vogue in up-to-date business and public service corporations.

The administrative control should be vested in ONE MAN, and, whatever his title may be, he should be a highway engineer with executive ability and versed in the principles of management. If the department be a large municipal or state department, it is particularly desirable that he should have had experience in the management and control of similar work where his training was not only in engineering, but embraced experience in the executive management of a large organization. This is simply going on the principle that from an administrative standpoint better and quicker results

can be accomplished by the selection of a man with previous experience than one who might have ability but who is not familiar with the work, and who would necessarily have to spend two or three years studying conditions before formulating his organization.

Disadvantages of Commissions. It is a great mistake to put this work under a commission of three, five or more men, as is the case in many states, counties and townships. In municipal departments there is hardly a commission controlling highway work, and the only reason that such a situation exists with reference to the state, county or township work is because these departments are newer and in many localities more of a political than a business undertaking. It is perfectly obvious that better results can be accomplished, and much quicker, by a single administrative head than thru a commission, and in this connection particular attention is called to the undesirability of having large boards of highway commissioners controlling the work of the townships.

The ADMINISTRATIVE FUNCTIONS embody general supervision over the appropriations and expenditures of the department. It is the executive's first duty to see that the appropriations are expended wisely and in an efficient and economical manner. He should also see that the public are kept informed of the manner in which the moneys are expended and the work is being carried on. It is also his duty and one of the administrative functions to see that the employees of the department are properly cared for and receive full recognition for their services. He must give constant attention to bringing about a spirit of coöperation among the employees. No organization will be as efficient as it should be unless there has been established a sort of *esprit de corps* among the employees. This is just as important as any other part of the work coming under the head of administrative control. It is also just as necessary to accord courteous treatment to the public, no matter what the source of their complaint or inquiry may be, in public business as it is in private business. Every communication should be answered fully and completely, and in this way the people will be given an insight into the public business and more readily appreciate the necessity of conducting it on a business basis. One of the administrative functions is to see that every employee is instructed to and does accord courteous treatment to everyone with whom he has any dealings.

Division of Responsibility. There is nothing more important in any organization than to fix the responsibility for the work coming under the supervision of the different functions of the organization. This does not mean it should be fixed only in so far as the head of the department or division and subdivision heads are concerned, but it should be passed right down the line so that each and every employee will bear his share. Therefore the proper arrangement of the division of responsibility for the work is one of the principal factors in any organization, as no matter how well the work may be systematized and how perfect may be the procedure, it will fail to accomplish its purpose unless each and every one of the employees is trained to accept responsibility for his part of the work.

7. Administration of Maintenance Work

General Considerations. Admitting that every department is more or less dependent upon a good organization, the condition affecting the operation and control of a large municipal, state, county or township highway department will be briefly analyzed. The greater part of the work coming under the jurisdiction of such a department, no matter how large or how small,

is or eventually will be, maintenance. Therefore, the success from this standpoint is probably four-fifths dependent upon the organization. It is not intended to underestimate the necessity for a good organization to handle the construction, but this work is of a somewhat definite character and there are more or less well defined principles that can be followed both from the standpoint of the office and field, while the maintenance work coming under the jurisdiction of a modern highway department, which usually embraces all branches of work that is logically highway work, or the care and control of the highways within the right-of-way, is an indefinite quantity. It is practically impossible to continuously and systematically maintain pavements and roads in first-class condition in an economical manner, without a good working organization built up along the lines best adapted to cope with the conditions involved in this important branch of work coming under the jurisdiction of a highway department.

Inadvisability of Separate Maintenance Division. It is not purposed to give the impression that the maintenance organization should be separated from the construction, as separate organizations are apt to result in an overlapping of jurisdiction and a tendency to shift responsibility, and open up a field for unlimited excuses as to whether the construction or maintenance division is responsible for any unsatisfactory conditions that may arise relative to the pavements. Furthermore, it is obvious that the logical organization to maintain the pavements is the one that saw them laid and is familiar with every detail of the construction, as very often a knowledge of apparently trivial conditions in connection with the construction bears an important part in the future maintenance.

The human element is also a most important factor in this question. Human beings are subject to influences, not only in so far as they affect the individual, but collectively, and there are conditions that will influence an organization striving to attain a purpose, to fall short of its accomplishment; as, for instance, where the construction organization is not charged with the responsibility of the maintenance, there is bound to be a subtle influence working, which, in a measure, will result in the construction division taking little or no active interest in a pavement after it has completed its work. This method of handling the work is not the best way to train engineers, as it limits their responsibility by cutting it off just when the opportunity presents itself to protect and care for what they have built, consequently their interest is bound to cease to a certain degree, and the organization loses that intimate knowledge of all the little details of the construction which play such an important part in future maintenance. It is the intimate knowledge of the details of both construction and maintenance, not considered separately but in their relation to one another, that is so desirable as a future guide in highway engineering, consequently the combination of the two organizations in one will accomplish far better results than they would working more or less independently, each with a limited responsibility. Highway engineering may be considered a specialty, but further specializing in construction and maintenance is not logical as the two are dove-tailed and cannot be considered separately. Every engineer engaged in highway work appreciates the fact that there is no such thing as a permanent pavement for either city streets or country roads, consequently, in addition to the cost of construction, the maintenance repair charges during its life must be included in the final cost and is a most important factor in the selection of a pavement. Therefore, it will be understood that any reference made to the organization of the department refers

to the one organization controlling all branches of the work, in a state, municipal, county or township department, even including street cleaning, which is a part of the maintenance work that should come under the jurisdiction of the highway department. The organization is assumed to be so constructed and operated that practically every member of the supervising force will be trained to supervise all the branches of the work and in this way the employees will become much more valuable to the department.

The activities coming under the jurisdiction of the municipal, county, township and state highway departments are not similar in every respect, but the principal functions do not differ sufficiently to affect the problem in the main. A large municipal department embracing street cleaning, collection and disposal of ashes, garbage and rubbish, and snow removal, together with the general problems, such as construction and maintenance of pavements, etc, embraces a greater variety of work than does a state department but principally of a nature that is essentially maintenance work. Likewise in a large state department, with an organization controlling a large area of improved highways, the maintenance problem is more involved and complicated than in county, township or state department with a less mileage of pavements or roads under its care, so that the perplexity of the problem increases not only with the number and variety of activities, but with the area of the territory and the mileage of roads and pavements coming under the jurisdiction of the department. It is, of course, a much simpler matter to cope with this problem where the work involved is such that it can be controlled from a central office, without delegating the responsibility to divisions and subdivisions of the organization. This is especially true in maintenance work, as there is always a tendency among engineers to be lax in attention to details of an apparently simple and routine nature. They are apt to overlook the fact that it is not difficult to construct a pavement as in supervising this work they are simply following more or less standard and well defined principles, where, in maintenance work, there is no set specification to follow, the success depending upon attention, to a certain degree, to daily routine and principally to petty details that present themselves in the actual physical work, and in this there is an unlimited field for initiative. The difficulty of impressing upon the supervising force the importance of close personal attention to detail in connection with the care of the pavements is one of the most important factors in the operation of a large highway department, and must be reckoned with and especially in these times, when the public is becoming more and more exacting and virtually demanding that the roads and pavements be kept continuously in good repair.

For convenience the different branches of maintenance work will be grouped under the following classifications: (1) Routine maintenance; (2) general maintenance; (3) emergency maintenance. For illustration, there will be considered only the more important functions under these classifications.

Routine Maintenance. This includes the cleaning of streets and this branch of work involves an enormous amount of petty detail that is only definite in character in so far as the schedule of cleaning is concerned, which usually calls for a general cleaning for each particular street every so often. The amount and character of cleaning, of course, is largely dependent upon the traffic, type of pavement, and density of population. Therefore, relatively speaking, from the standpoint of the state or county highway department, this problem is a comparatively simple one, consisting primarily of the cleaning of country roads, which work embraces scraping of the shoulders and keeping the gutters open. The magnitude of the problem

varies with the area to be covered and the density of population in a given area; from a more or less simple one on a given country road, it looms up into a very important one in a state highway department, and likewise, from the cleaning of a given street in a small town, it looms up into one of the most important problems in a large municipality; and both with regard to the state and municipal highway department it is largely a question of organization. Once the organization is perfected from an administrative standpoint, the work is two-thirds completed. The main problem in routine maintenance of this character is to organize a working force capable of performing the work along the lines of least resistance in an efficient and economical manner.

General Maintenance. This includes street repair work which is of a distinctly variable quantity and unlike routine maintenance must be coped with by an organization of an entirely different kind from that for street cleaning, which organization consists of a regular working force employed all year round and of a more or less military character. The street repair work is usually divided into three classes: (1) Block pavement repairs; (2) cement-concrete pavement repairs; (3) bituminous pavement repairs; (4) macadam, gravel, and earth road repairs, and (5) bituminous surface treatments. These classifications involve different characters of work, each requiring special knowledge on the part of those engaged in the actual performance of the physical work. Stone block, wood block and brick repairs, for example, require skilled laborers who have made a specialty of this work and are employed under the title of pavers and rammers; while repairs to sheet-asphalt and other bituminous pavements must be performed by men specially trained in this line of work, in addition to the necessary force engaged at the mixing plants. Broken stone road repairs, the care of earth roads, and bituminous surface treatments, also require men specially skilled, and while it is desirable to train the gangs for each particular branch of work under this classification, these subdivisions can be handled by those directly in charge of this division by training the laborers for the particular work to which they are assigned. It readily will be seen that this force, in the first place, can only be employed when the weather conditions are favorable for the work which makes the organization much more difficult to control and keep up to a proper standard than one composed of men regularly employed all of the year. Moreover, the indefinite character of the work necessitates greater elasticity in the organization than does street cleaning, and makes it a still more perplexing organization to operate with success.

There is no definite schedule for a street repair maintenance organization to work on, and there are no fixed rules that can apply to all repair work other than that when repairs are required, they should be made at once. The materials to be used and the method and manner of making repairs are variable quantities for which only general principles can be set forth, which, of course, means that the organization coping with the work must be well trained. Work of an indefinite character opens up a channel for innumerable excuses and to be successfully coped with, requires a certain amount of initiative on the part of each and every man from the laborers to the chief engineer, which makes their good will a necessary adjunct. The men should be taught to understand the relationship between their particular function and the work as a whole. This can be brought about thru the installation of unit cost records, which, together with an educational campaign, consisting of meetings held every so often for the purpose of making clear the method of handling the work and each man's part in the

work, will bring about a friendly rivalry between the different repair gangs. These meetings mean a great deal, as they set the men thinking, open up a new vision to them, and put them on their mettle, which will ultimately result in improving their opportunities.

Emergency Maintenance. This includes snow removal, and it is unnecessary to dwell on the fact that no matter what appliances may be on hand for the removal of snow, the actual performance of the work is dependent upon the efficiency of a thoro and systematic planning of the operations, dividing and subdividing the territory into sections covering areas of such a size that the work can be thoroly and readily controlled by the supervising force. This work arises suddenly and must be performed in such a short space of time that it requires more supervision probably than any other branch of work, and it is for this reason it can be better and more quickly handled by so dividing that each and every one controlling the work will be responsible for a certain definite area. This principle is true of any city, independent of its size. The supervising force selected to control the work must be thoroly instructed, before the winter sets in, and imbued with a spirit of enthusiasm and pride in their part of the work. They must be available at all times, day and night, keep track of the weather conditions thru the main office where the latest weather reports should always be available, and, as soon as the indications point to a storm, each and very one in the organization must set to work to get his equipment out on the street at the earliest possible moment. This necessitates getting in touch with the contractor's teamsters, etc, and all the men assigned to a district in order that they may start out immediately the snow shows signs of making any headway which means, of course, as soon as it begins to cover the pavements. From that time on, the whole organization must work day and night fighting the storm.

8. Methods of Systematizing Work

Systematizing the work requires a very careful study of all the activities of the department from the ground up and their relation to one another, as the primary consideration should be to do away with as much unnecessary routine as is possible and still have an adequate system of control and one that embodies the compilation of all relevant data of value as a permanent record. Systematizing means simplifying the work, the bringing about of a maximum of efficiency with a minimum of energy. In a highway department, where the activities are so closely related that there is very apt to be an overlapping of jurisdiction and duplication of work, it is obvious that a thoro systematizing of the work is essential.

The tendency is to standardize and control work in a manner that will not only conserve energy and do away with unnecessary duplication, in so far as individual effort is concerned, but to concentrate our forces so that we can efficiently and economically carry on our operations along the line of least resistance, as ease of operation is one of the most important factors to be considered in any working organization, and, for example, in a municipal or town highway department, there is no step that would accomplish more in this direction than the combination of the highway construction, maintenance, street cleaning, and the collection and disposal of ashes, rubbish and garbage, under the jurisdiction of the one organization. This would also have the added advantage of placing the street cleaning work more generally on an engineering basis, which would undoubtedly lead to more sanitary methods of cleaning, and to methods that would be more apt

to take into consideration the maintenance and care of the pavements themselves than is likely to be the case where the street cleaning is not under engineering supervision.

Systematizing of the work and establishing a sort of *esprit de corps* are both essential adjuncts to an efficient and economic administration of a highway or any other department. Numerous highway departments have men who are loyal and enthusiastic, but their work is not conducted on an efficient and economical basis because it is not systematized. The best method of establishing a permanent spirit of coöperation is brought about thru arousing the interest of each and every employee, high or low, thru establishing a definite procedure to govern each function and operation. Under such a system, each employee assigned to any subdivision or operation coming under the jurisdiction of the department will immediately inquire what relation his task has to the work to which he is assigned. This will lead to his studying the forms, charts, etc, and will naturally arouse his interest, and therefore a thoro systematizing of the work and a definite procedure governing each and every operation is essential.

In order to illustrate this point, let us consider for example the effects on an organization of establishing a definite procedure for the work of the maintenance forces. Under the old system the foreman kept the time of the men and noted the material received for the work and after the job was completed, the unused material, if any. This account he turned in to the main office. He was responsible for the time the men put in on the work and the amount of work performed. No records, however, were kept permitting an analysis of the efficiency with which this work was performed so that the foreman had no means of knowing whether he was performing his work in an efficient and economical manner. Under the circumstances it is perfectly natural that his one object was to turn in the time of the men and to perform the work, not necessarily in the shortest time possible or at a reasonable cost. Now, as soon as a definite procedure is installed to control such work, the foreman is given job orders or route sheets noting the work he is to do and the order in which it is to be performed; the time sheets, thru which the time of the men is kept and charges against the specific parcels of work; material sheets, thru which the material is charged up in the same manner; all of these are designed to bring down the cost of the work to a unit square yard basis, both with reference to cost of material and labor. At first these forms and records are apt to confuse the old type of foreman, but after he has been thoroly instructed in their use and has been using them for a time, it will be found that he is more enthusiastic over the work than he has ever been, and has inculcated this spirit in the laborers in his gang, with the result that not only is the work done at a lower cost but it is done in a more efficient manner.

The general principles set forth in the outline of the several procedures, such as planning boards, correspondence, contracts, unit costs and permits and licenses, as described in Arts. 9 to 13 inc, can be utilized in any highway engineering organization by making the necessary modifications to suit the conditions under which the respective departments intend to or are operating.

9. Planning Boards and Visible Records

As a means of insuring a more thoro and intimate knowledge of the status of the operations coming under the jurisdiction of a large highway department than that afforded thru up-to-date records and definite procedures

for each operation, it is necessary to supplement these records and procedures with planning boards, containing a graphic representation of the status of the operations in such a manner that the work can be more readily controlled than is possible where it is necessary to constantly refer to office records. No matter how thoroly the operations of a highway department may be systematized, where the heads of the different units of the organization are dependent upon daily consultations and studies of the records on file to enable them to picture in their minds the status of the work under their jurisdiction, there is always a certain amount of lost motion and unbalancing of the work, resulting in one locality receiving undue consideration at the expense of another or delays in the starting of important contracts due to unconsciously yielding to outside influences interested in pushing forward less important work. This new scheme for controlling the work of a department thru visualizing the operations enables the executive and division heads to at any time obtain a picture of the status of the operations coming under their respective jurisdiction, and is the most-up-to-date system heretofore employed in highway departments or industrial corporations to simplify carrying on the work in an orderly and systematic manner. Planning boards have, after a thoro trial, proved an unqualified success and one of the most practical means that have been thus far developed for simplifying the management of such a department.

This method of visualizing the status of the work also enables the executive to readily give information concerning the operations under his jurisdiction that would ordinarily necessitate communicating with the offices where the records are kept, resulting in a delay of several minutes before the information could be obtained from the record files.

Philadelphia Bureau of Highways Planning Boards. The following principal objects were sought in connection with the installation of the system of planning boards in Philadelphia by the author while Chief of the Bureau of Highways and Street Cleaning, 1912 to 1917:

1. The establishment of a means of providing the chief engineer, the division engineers and the several district assistant engineers and their subordinates with a continuous and complete, concise and easily accessible graphic record of all authorized prospective construction and maintenance work, and of the current status of all work under contract or in course of prosecution under their respective supervision, in order that they would be enabled to plan and administer the work in a more systematic, economical and efficient manner.
2. To eliminate as far as possible the necessity for the engineers to make daily or perhaps constant reference to, and studies of, the regular filed office records in order to enable them to form a mental picture of the status of the work under their jurisdiction.
3. The institution of a practical means of controlling or equalizing the quantity of work to be performed in different localities, and in determining the sequence in which the work could be prosecuted to the best advantage, and to assist in the subsequent assignment or distribution of the engineering, inspection and working forces.
4. To facilitate the prompt determination of any general information relating to the construction and maintenance work that may be sought by the public and that otherwise would not be available except after more or less detailed investigation with a resulting consumption of time.

Equipment. The equipment which has been provided in connection with the planning board system includes the following:

1. Planning Boards, which have been installed in the offices of the chief engineer, the 2 division engineers and the 7 district assistant egnineers in charge of general highway work and the division engineer in charge of bridge and sewer maintenance.
2. Legends, which while standard in all possible details, necessarily vary more or less in order to adequately provide for the specific data indicated on the four general modifications of the planning board in use.

3. INDICATORS, pins and thumb tacks of various sizes, shapes and colors suitable to indicate the designations shown on the legends.

4. CURRENT STATUS VISIBLE RECORDS, two forms, one each respectively for contract work and for municipal force work, and one form for extensive special construction work for the information of the chief engineer; and one form in three parts for the use of district assistant engineers. Upon these several forms are indicated the pertinent details and the current status of all work authorized, under contract and in course of prosecution.

5. CURRENT STATUS RECORD FILES, which consist of a visible card filing device for the chief engineer's office and clip filing boards in the offices of the district assistant engineers.

6. DAILY PROGRESS REPORTS, which indicate daily both graphically and analytically the nature and quantity of work performed and other pertinent data for each job.

General Construction of the Planning Boards. In general, the planning boards consist of a map enclosed in a wood frame, of either the entire city or the portion included in the district or division under the respective engineer's jurisdiction. The scale of the map is made sufficiently large to permit the necessary details to be shown with ample facility. The maps on the planning boards in the offices of the chief engineer and the division engineers are drawn to a scale of 1000 ft to the inch, while those in the offices of the district assistant engineers vary between 200 ft to the inch in the congested central districts to 500 ft to the inch in the outlying districts. The enlargement of the scales of the several district planning board maps is due to the need for a greater space in which to record the more refined details which it is essential should be known and reckoned with by the district assistant engineers, but which need not, however, be considered in such detail by either the chief engineer or the division engineers. The maps contain, for the territory covered, a complete and accurate record of the highways physically opened and also of those not physically opened but on the city plan. On all physically opened highways, the characters of the existing roadway pavements are indicated by colors. Where a highway contains two or more varying types of pavements, that is, the gutter or track pavements differing from that of the shoulders, the actual existing pavement conditions are indicated on the district assistant engineers' maps by properly coloring the relative portions of the highway. The fact of a pavement being under maintenance guarantee is indicated by wide pencilled hatching superimposed on the character of pavement coloring and which is erased upon the expiration of the guarantee period. The existence of railway tracks is indicated by solid black lines upon which is placed a symbol indicating the name of the ownership. A single line indicates a complete track structure and the number of separate complete track structures existing on a highway is indicated by a corresponding number of single lines. The maps are securely mounted with paper-hangers' paste upon a wood fiber board $\frac{3}{8}$ in in thickness, which is securely nailed to the wooden backing of the frame enclosing the map. The planning board is fastened securely to the office wall and in such a position that it may, if possible, be adequately illuminated by daylight, and that shadows will not interfere with its operation. Where artificial illumination is required, this is supplied by means of a special trough mirror reflector containing a number of switch-controlled tubular tungsten electric incandescent lamps and concealed in the canopy at the top of the planning board frame.

Legends. In devising the legends (see Fig. 6) an effort was made to have them mnemonic, that is, to assign indicators of such shapes, sizes and color as would by their appearance readily associate themselves with or identify the work or condition they were intended to represent. All data or information of a fixed or semi-permanent nature is indicated by properly colored and specifically symbolled circular flat-headed thumb tacks which are inserted flush with the surface of the map. In order to facilitate reference to information in greater detail, these indicators also each contain an identifying serial number which refers to lists annexed to the planning board which indicate full information relative to definite locations, names of ownerships, etc. All data or information of a temporary or variable nature is indicated by means of colored glass-headed pins. Three sizes of pins, as relating to the size of the glass head are used, but all of the pins have short stems which permit the glass head being inserted close to the map surface. In instances where two or even three conditions need be indicated by a single pin, this is accomplished by using pins whose heads contain two or three properly colored concentric circles.

LEGEND

PERMANENT DESIGNATIONS

GENERAL:

- (Red) Main Highway Office
  NOTE: In the following indications, the numerical designations of districts are indicated by numerals.
- (Red) District Highway Office
- (White) Service District. Street Cleaning and Ash, Rubbish and Garbage Collection
  NOTE: In the following indications, the serial identification numerals refer to correspondingly numbered detailed notes on lists annexed herewith.
- (Blue) Store Yard
- (Yellow) Dump, Ash Rubbish or Street Dirt
- (Yellow) Garbage Disposal Plant
- (Yellow) Rubbish Disposal Plant
- (Yellow) Stable, Service Contractor's
- (Black) Contractor's Asphalt Plant
- (Black) Municipal Asphalt Plant

EXISTING PAVEMENTS:

- (Blue & Black) Asphalt Block
- (Gray) Bituminous Macadam
- (Green) Cement Concrete
- (Pink) Cobble or Rubble
- (Blue) Sheet Asphalt
- (Red & Black) Slag Block
- (Purple) Stone Block
- (Yellow) Unimproved, Graded, Dirt, Cinder, etc.
- (Red) Vitrified Block
- (Brown) Waterbound Macadam
- (Black Hatched) Wood Block

MISCELLANEOUS:

- (Black & White) Railroad Siding
- District Boundary Line

TEMPORARY OR VARIABLE DESIGNATIONS

CHARACTER OF AUTHORIZED CONSTRUCTION WORK:

- (Yellow) Grading

PAVEMENT:

- (Gray) Bituminous Macadam
- (Green) Cement Concrete
- (Blue) Sheet Asphalt
- (Purple) Stone Block
- (Red) Vitrified Block
- (Brown) Waterbound Macadam
- Wood Block

INDICATION OF LIMITS OF WORK:

- If Highway is not Colored
- If Highway is Colored
- If necessary in conjunction with the previous indications to show limits of contiguous authorizations.
- (Yellow) If Work is that of Surface Treatment

WORK DETAILS:

- (Red & Yellow) Urgent necessity for prompt performance of work
- (Black & Yellow) Materials Ordered
- (Black & Yellow) Materials Delivered
- (Black & White) Contractor's Asphalt Repairing Gang: General Working Location
- (Black & White) Municipal Asphalt Repairing Gang: General Working Location

MISCELLANEOUS:

- (Black) Ordinance pending to authorize Work
- (Yellow) Outstanding Tickler. Indicating the existence of open relative correspondence

DETAILED INFORMATION:

Full detailed information relative to the current status of the legal, contract, structural and other governing conditions pertaining to all work posted on this planning board is indicated on the individual card records for each specific authorization in the Current Status file.

TECHNICAL CLASSIFICATION AND STATUS OF WORK

CONTRACT WORK:

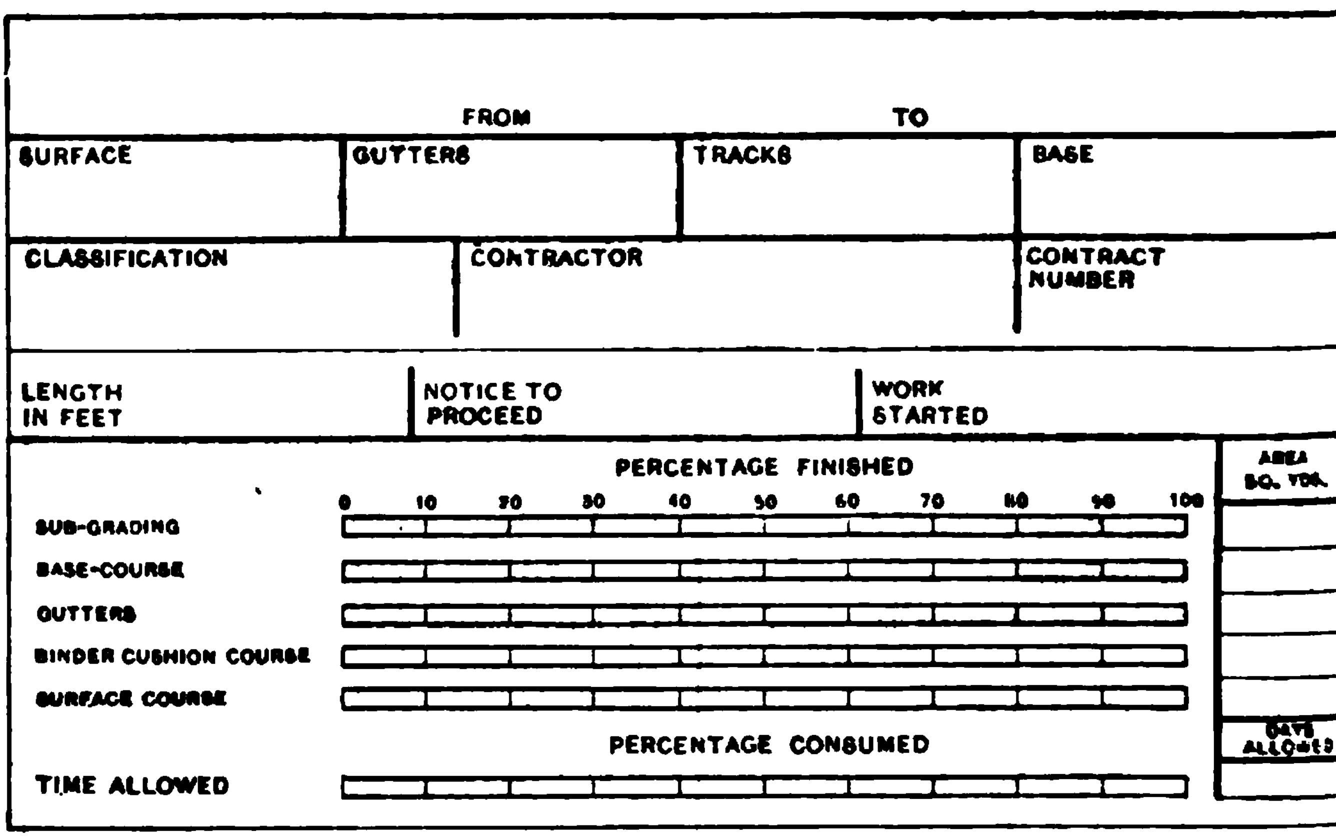
	Authorized	Contract executed or in course of execution	Work in progress by contractor	Authorized but cannot be placed under contract for cause	Under contract but work cannot be started for cause	Work started but is now suspended for cause
Grading	(Light Green)	(On White)	(On Red)	(On Black)	(On White & Black)	(On Red & Black)
Paving	(Red)	"	"	"	"	"
Repaving	(Blue)	"	"	"	"	"
Surfacing	(White)	"	"	"	"	"
Resurfacing	(Brown)	"	"	"	"	"
Special Construction Work	(Dark Green)	"	"	"	"	"

MUNICIPAL FORCE WORK:

	Scheduled	Work in progress by Municipal forces
Extensive Surfacing, Resurfacing and Repaving	(Gray)	(On Blue)
Dust Layer Treatment	(Crystal)	"
Bituminous Surface Treatment	(Yellow)	"

Fig. 6

Operation of the Planning Boards and Current Status Records. The responsibility for the prompt and accurate posting of the planning board and current status file is centralized in one person in each office, and this posting is done early each morning from the reports received of the operations, transactions, and changes in conditions occurring since the time of posting on the previous day. The posting is done by the insertion or removal of pins of the proper shape, size and color. In the district offices, however, the record of the need for the performance of any character of repair work is posted as soon as the necessity becomes apparent from any source, such as being reported by a patrol inspector; resulting from observation by the district assistant engineer or any of his subordinates; notice from the main highway office or any other municipal department, from the police or from the public. Where two or more different characters of pavement exist upon a highway, the indicator pin is placed upon that portion of the highway which indicates the character of pavement requiring the repairs which may be the track, the shoulder or a gutter. All instructions from the chief engineer or the division engineer to the district assistant engineers to investigate conditions or perform any work at a definite location are posted on the planning board



Form A

as an outstanding tickler which constitutes a current record of all such matters not closed out by a final report to the main office. The trouble marker is used to indicate any retarding condition relating to either an administrative detail or the physical work, such as legal obstacles preventing authorized work being placed under contract and delays, interruptions, or suspensions of work in progress, etc. Of course, all indicator pins are removed immediately after the indicated conditions are found no longer to exist. When the finished work is that of original pavement or such other work as results in a change in the character of an existing pavement, the map is posted by being properly recolored to indicate the new type of pavement surface.

Routing the Repair Work. In the several district highway offices and in the division of bridge and sewer maintenance, the daily route sheets indicating the work to be performed by each municipal repair gang are prepared by direct reference to the planning board, where every condition such as general repairs to a street or even an isolated defect in a pavement is specifically indicated and in the order of their importance. The routing of the repair gangs is one of the most important functions of the planning board. The pins indicating work in progress by the municipal forces also contain a serial number which identifies the name of the gang foreman in charge of the work.

Current Status Records. In addition to the data regularly carried on the planning boards there is also certain other data of a more detailed and extensive nature relative to the current status of the legal, contract, structural, and other governing conditions,

which should be readily accessible but which on account of their multiplicity it would not be practicable to indicate on the planning board. This information is recorded in a very accessible manner by means of individual card records properly filed in visible filing devices which are located adjacent to the planning boards. Three forms of current status card records are provided, one form being for municipal force work and one form for contract work, both of which are used in the chief engineer's offices. These records are so designed as to permit the indication in a concise manner and in logical sequence of all the pertinent information relative to current conditions. The design of the current status record form used in connection with the district planning boards is such as to make it possible to post graphically from the inspector's daily progress reports, either daily or weekly as may be desirable, the percentage of each portion of the work finished and the percentage consumed of the total time allowed for the completion of the work (see Form A).

Inspectors' Daily Reports. Each inspector having supervision of construction or maintenance work is required to submit daily reports in such detail that, in addition to their other purposes of record, they furnish the data necessary to the prompt current posting of both the planning boards and current status records. The daily progress report on each job as submitted to the division engineer by the inspector is printed on a postal card and the most recent one of the reports for each job is daily inserted on a visible filing board, thus constituting an economically operated current status record.

10. Unit Cost Records

Unit cost records serve as a basis for determining upon future appropriations. They also serve as a means of control over the operations of the department, bringing out the strong and weak points in the organization and the economy and efficiency with which the work is being performed, both by comparing the different units of the organization with one another, and the different characters of work of the department with different units of the organization and like work in other localities.

These costs, principally in repairs to pavements, bituminous surface treatments, street cleaning, and other classes of work that can better be done by day labor forces, employed directly by the highway departments, than by contract, will be a most important factor in enabling any department to make greater strides toward putting this work on an efficient and economical basis. Records of this kind are invaluable as a means of control in conducting work coming under the jurisdiction of any highway organization, and will result in bringing about a spirit of rivalry between the different subdivisions and units of the organization.

The moral effect on an organization is alone a justification for keeping unit cost records. This is illustrated thru the pride aroused in the men in connection with their work. The natural instinct of man is to excel in his undertakings, but we must remember that men will be led and not driven, and if we are to get the best out of them we must arouse their interest in their work and impress them with a sense of their responsibility and there is no better way to do this than thru the friendly competition resulting from the use of the unit cost records.

In some quarters there has been a rather general impression that the necessary job orders, route sheets, time sheets, material reports and progress reports which the foreman is required to handle, are apt to confuse him and consequently tend to decrease rather than increase the efficiency of his work. This is not so; on the contrary it tends to develop the foreman, awaken his interest, and in many instances makes a new man of him because he is placed on his mettle, taken in to a certain extent on the financial and business end, made a more important factor in the organization, and consequently his work means more to him than the mere physical results.

Value of Unit Costs. To insure the efficient administration of any commercial or engineering organization, certain well-defined fundamental laws of management must of necessity be recognized and adhered to. Among the foremost of these laws is the one emphasizing the importance of a determination of the unit costs of performance or production. An organization and its administrative equipment may presumably be ideal in every respect and yet in the final analysis not produce the results or accomplish the purpose for which it was created. It is a knowledge of the unit costs of the organization's performances that places the executive or managing officer in possession of the facts it is most necessary and essential he should know. As unit costs constitute an absolute and true index of the relations between funds expended and results accomplished, this subject in so far as it relates to public work activities is properly becoming more and more the concern of a critical public.

An illustration of the advantage of keeping records of this kind was in connection with the bituminous surface treatment work, which is the principal factor in modern highway maintenance of water-bound macadam streets and roads, in Philadelphia during 1913 and 1914. The unit cost records of this work formed in 1913 showed an average cost of 7.3 cents per sq yd, while in 1914, the average cost was 5.8 cents per sq yd, or a saving of 1.5 cents per sq yd over 1913. This saving was a direct result of making an analysis of the items of cost for 1913, thru which it was possible to point out the weak points in the performance of the work, with the result that in 1914 more attention was given to the different operations of the work, the cost of which was considered to be too high the previous year. Of this saving of 1.5 cents per sq yd, about 0.5 cent per sq yd was due to the fact that a number of the treatments were second applications and naturally required a lesser amount of bituminous material per square yard, and the reduction in the cost of gravel, but approximately 1 cent per sq yd, or a saving of 14% of the entire cost of the work, was entirely due to the increased efficiency of the organization in handling the work.

Information Obtained from Unit Cost System. Aside from furnishing data calculated to justify or discredit the existence of an organization, or the outlay of funds for the accomplishment of a definite function or purpose, unit cost reports assist in determining certain matters of policy and administration. The maximum possibilities of a unit cost system naturally vary with the conditions existing in the organization in which it is operated. In installing the unit cost system the following objects should be sought:

1. To ascertain the quantity, and total and unit cost of each class of work performed, which will provide data to facilitate the preparation of budget and prospective work estimates and also afford a basis from which may be determined the fairness of unit prices bid on contract work.

2. To provide data to assist in the determination of the time beyond which it would be undesirable for economic reasons to continue maintenance work on existing roads or pavements, or in other words, the time when replacements must be contemplated.

3. To secure by interpretation of the data, knowledge as to the efficiency of performance of a department's forces, and to assist in showing the adequacy of the service rendered to the public.

4. To show the quantity and cost of each class of work performed within the boundaries of any district, or unit length of highway, or on any specific structure or job.

5. To show separately the varying and principal elements of expense, such as labor, hauling and materials, entering into the cost of each class of work.

6. To produce in the subordinate employees the beneficial moral effect resulting from a realization that records of their performances are brought to the attention of their superiors.

7. To promote friendly competition between similar units of the organization and establish a sort of *esprit de corps* among the men.

As in most localities the construction of highways is under contract, all the work performed by the department forces is that of maintenance. It is possible to design a standard unit cost system sufficiently flexible to permit its application to any class of maintenance work. The principal general classifications into which the maintenance work performed by department forces is divided, and for each of which a complete distinctive unit cost system should be provided, are as follows: (1) Highways; (2) street cleaning; (3) bridges.

Unit Cost System for Maintenance of Highways. Except in minor details the procedure for each of these systems is similar. Considering this, and also the fact that while the procedure for the highway maintenance repair unit cost system includes greater variations from the standard, and at the same time also embodies all of the standard principles governing the systems for the remaining classifications, these will be omitted in favor of a description of the general conditions and considerations governing the highway maintenance repair unit cost system, in a large municipality, which, with the necessary modifications, can be used for a state, county or township highway department. This work should be subdivided into two general sub-classifications as follows:

1. Restoration work, which includes the replacement of highway pavements opened by individuals or public utilities, for which the municipality receives remuneration, and the replacement of pavements opened by any municipal department.

2. General maintenance work, which includes all work done on the highways and not included under (1).

To facilitate the reporting of field data, the work included in the two preceding general sub-classifications should be divided into the three following divisions:

1. Restoration and maintenance of streets.
2. Restoration and maintenance of roads.
3. Bituminous surface treatment and sprinkling.

Maintenance Chargeable to Different Funds. All of the work performed in a municipality, both restoration and maintenance should be chargeable to either of the two following funds. (1) City fund; (2) street railway assessment fund. This division of funds is occasioned by the fact that in some municipalities the street railway companies pay annually to the city a fixed amount to compensate the municipality for the maintenance and replacement of roadway pavements on the highways occupied by their tracks. The fact as to whether or not the highway on which the work is performed is occupied by the street railway company's tracks should be reported by the foreman in charge of the work and this should govern the fund against which the work is charged.

KINDS OF FORMS USED. To provide for the operation of the unit cost system and the attainment of the objects for which it is instituted, the following set of forms should be provided:

1. A schedule of mnemonic symbols representing each and every class of work likely to be encountered.

2. Daily route sheets, one each for restoration work and maintenance work respectively.

3. Material issue orders.

4. Composite labor, material, hauling and progress record forms, one each for pave-

ment restoration and maintenance; road restoration and maintenance; and, surface treatments and sprinkling, respectively.

5. Cost record forms.

6. Highway maintenance record forms, one each for blocks and intersections respectively. Note: For the purposes of the maintenance records a block is considered to be a length of highway lying between the near curb line of the two nearest main intersecting highways, and an intersection is considered to be that portion of the main intersecting highways lying outside of the curb lines.

7. Printed instructions, enclosed in a pocket folder, explaining in detail the use of the forms and the general operation of the system.

To insure universal and definite knowledge concerning the operation of the unit cost system, every employee having to do with the system should be provided with a schedule of work symbols (see Form B) and a set of written instructions (see Form C).

On all of the forms, two colors of ink should be used in column headings, red indicating that the data will be supplied by the office, and black indicating that it is to be supplied by the gang foreman. Wherever practicable the data supplied by the office should be typewritten. Gang foremen should not be permitted to make or keep any records concerning the work except on the indicated forms and these entries should be made while actually engaged on the work.

Field Use of Forms. Except when a longer period of time is required to finish a specific parcel of work, the gang foreman should be provided each day, by the district office, with a Route Sheet, Form D, indicating the location and order in which the work is to be performed that day, separate forms being used for restoration work and maintenance work respectively. For each class of work the gang foreman should enter the work symbol and the length, width and area of the work performed. Upon completion of the work, he should sign and transmit this report to the district office for approval by the district engineer, who should then forward it to the main office.

On the first day of each week each gang foreman should be furnished with enough copies of the Time, and Progress and Material Sheet for that week. These forms should contain the district number and date, and the name, position and rate of pay of each employee in the gang. During the progress of each day's work the following data should be recorded on these forms by the gang foreman: the work symbol, placed in the spaces headed Order No., the fund, the time of arrival and departure on the job of each workman and team, the location of the work indicated by block or intersection, the length, width and area or thickness of work performed, the quantity and character of materials received and used, and the number of hauling trips made. After being signed by the gang foreman this report should be transmitted to the district office for the approval of the district engineer, after which it should be forwarded to the main office.

When it is necessary to use materials from stock the gang foreman should originate a Material Issue Order prepared in triplicate, upon which is printed "Please issue the following stores to bearer" and in addition, each copy should contain the following data: the district number, the date, the serial number, the name of storekeeper, the work symbol, the quantity, unit and description of material and the day and hour that the material is wanted, which is the time the team or agent leaves the job for the storeyard. The duplicate copy of the material issue order should be retained by the gang foreman and the original and triplicate copies presented by the driver or agent to the storekeeper who should record the time the team arrives, the time of issue of material to driver and the time the team departed, and should retain the original and return the triplicate to the driver for transmittal to the gang foreman, who should record the time of the receipt of the material and time of the hauling vehicle's arrival at the job. After being signed by the gang foreman the material issue order should be transmitted to the district office to be approved by the district engineer, and then forwarded to the main office. Whenever possible, however, the material issue order should be approved by the district engineer prior to its being sent to the storekeeper. The original copy of the material issue order which is retained by the storekeeper should be used in the posting of the balance of stores records.

Office Use of Forms. Upon the receipt of the record forms at the main office the entries on the time, progress and material sheets and on the material issue orders should be extended and totaled by the cost clerk, and, after being forwarded to the paymaster for his record of the employees' time, and returned, the following data should be entered on the Cost Record cards (see Form E) one of which should be originated for

each highway intersection and block; the district number, the work symbol, the fund, the date, the location, character and quantity of work performed, the foreman's name and the costs of labor, material and hauling. At the termination of any desired period of time there can be readily compiled from these cost records, the unit costs of any class of work performed in any geographical division, or the unit costs of the performance of any unit of the organization. With respect to classes of work where it is desirable to maintain cost records in greater detail as in the case of bituminous surface treatment work, these cost data may be readily compiled from the data reported on the time, progress and material reports.

From data contained on the Route Sheets received at the main office there should be noted on the reverse side of the Highway Maintenance Record cards which contain a detailed sketch, drawn to a standard scale, of each block or intersection, a record of the character, area and a graphical sketch of all pavement restoration and maintenance work performed on a number of the typical streets of each class of pavement that have not outlived their economical life. This makes it a simple matter to determine how the repairs are wearing as a repair over a previous repair would be brought out in the plotting. Where it is decided that it would be more economical to repave instead of repair a pavement, the repairing done pending the appropriation of funds for repaving should not be plotted, as the plotting is intended to serve only as a guide until the pavement has outlived its economic life.

A separate card should be provided for each block and each intersection of highway pavement. These records contain on their face side a record of the character and unit costs of the base and surface courses of the original pavement, and the name and address of the contractor, the dates of completion and guarantee expiration and the length of guarantee. At the close of each year from the data shown on the Cost Record cards for each highway block and intersection there should be recorded on the corresponding Highway Maintenance Record, the following data: The year, the total area repaired, the total and unit costs of pavement replacements made necessary for both restoration and maintenance, the total area of restoration work only, and the unit replacement cost per year per square yard of pavement covered by the record. These maintenance records will eventually serve as a basis upon which the discontinuance of maintenance and the need of entire pavement replacements should be determined.

Form B. Schedule of Mnemonic Symbols for Work Performed by Municipal Forces

B S.. Brick on sand
B C.. Brick on concrete
G S.. Granite block on sand
G C.. Granite block on concrete
S S.. Slag block on sanp
S C.. Slag block on concrete
C..... Cobble
M P.. Water-bound macadam patching
M R.. Water-bound macadam resurfacing
M S.. Water-bound macadam surfacing
B G.. Brick gutters
R...... Rubble
G L.... Granolithic
A B S... Asphalt block on sand
A B C... Asphalt block on concrete
A C.... Asphalt on concrete
A B.... Asphalt on bituminous base
A S..... Asphalt on broken stone
B B G.. Belgian block gutters, which includes granite and bluestone
R G.... Rubble gutters
C G.... Concrete gutters

Surface Treatment and Bituminous Patching Work	Treating Water-bound Macadam Roads	Treating Bituminous Macadam Pavements	Patching Water-bound Macadam Roads	Patching Bituminous Macadam Pavements
With Tarvia A................	T A M	T A B	P A M	P A B
With Tarvia B................	T B M	T B B	P B M	P B B
With Tarvia X................	....	....	P X M	P X B
With Ugite No. 1 (cold)............	T U 1	....	P U 1	....
With Ugite No. 2 (hot)............	T U 2	....	P U 2	....
With asphalt cut-back............	T C M	T C B	P C M	P C B
With calcium chloride............	T C C	....	....	....
With road oil................	T R O	....	....	....
With Glutrin	T G	....	....	....

	Earth Roads	Macadam Roads
Cleaning gutters	C G D	C G M
Cleaning roads	C R D	C R M
Cleaning and shaping shoulders	C S D	C S M
Cleaning trunks, drains and inlets	C T D	C T M
Repairing trunks and drains	R T D	R T M
Building, constructing or placing trunks and drains	B T D	B T M
Water sprinkling—W S C—Cinder roads	W S D	W S M

G R: Repairs to guard rails, fences and other safety devices.

X: Any miscellaneous work not described above which should be further described under miscellaneous work on the progress and material sheet.

Form C. General Instructions to Employees Relative to the Operation of the Unit Cost System for Work Performed by the Municipal Forces in the Philadelphia Bureau of Highways

INSTRUCTIONS TO THE DISTRICT ASSISTANT ENGINEERS. *General:* 1. To insure a uniform and definite knowledge concerning the operation of the unit cost system, each employee having to do with the system must be provided with a copy of such portions of these instructions as may be necessary to the proper performance of the portions of the work done by that individual employee.

2. In these instructions the term "foreman" means the person in the field directly responsible for the work performed by the gang.

3. On the forms where two colors of ink have been used in column headings, red indicates that the data must be supplied by the district office and black indicates that it may be supplied by the foreman.

4. Wherever practicable the data supplied by the district office should be typewritten.

5. Each foreman should send in his report forms daily and these should be promptly approved by you and transmitted at once to the main office.

Character of Work Symbols: 6. Provide each foreman with a schedule of mnemonic character of work symbols and instruct him in their use.

7. The proper character of work symbols must be given on all route sheets issued to foremen.

8. See that the proper symbol is entered in every instance on each of the several forms where it is necessary to identify the expenditure of any labor, hauling or material with the character of performance necessitating it.

9. In the case of restoration work, it is necessary also to properly identify the work performed with the reason that made it necessary, and therefore there must be indicated in addition to the character of work symbol, the permit serial number preceded by either of the symbols "W," "P," or "X," which indicate respectively that the opening was originally made by the Bureau of Water; a public utility or individual which has paid a flat rate charge; or, some agency other than the two previously enumerated.

Route Sheets: 10. Except when a longer period of time is required in which to finish a specific parcel of work, you must furnish to each foreman for each day, a route sheet, indicating the district number, the date and the location, character symbol and order in which the work for that day is to be performed.

11. Separate forms must be used for restoration work and maintenance work respectively.

Material Issue Orders: 12. See that each foreman is at all times provided with a book of material issue orders and that they are used in obtaining all materials from either the storekeeper or other foremen.

13. You should be thoroly familiar with the manner in which material is being ordered and handled.

14. Books returned by foremen containing triplicate copies of material issue orders are to be filed in the district office.

Time, Progress and Material Sheets: 15. See that on the first day of each week each foreman is furnished with enough copies of the time and progress and material sheets for that week, separate forms being used for each of the following general characters of work: (a) City street pavement restoration and maintenance; (b) country road pavement restoration and maintenance; (c) bituminous surface treatment and sprinkling.

16. On these forms the district office must indicate the district number, the date and the name, position and rate of pay of each employee in the gang.

17. On sprinkling work, the number of gallons of water used should be indicated by the district office, as determined by knowing the capacity of each sprinkler and the number of loads consumed.

19. For the purpose of the unit cost and maintenance records a block is arbitrarily considered to be a length of highway lying between the near curb lines of the two nearest main intersecting highways; and an intersection is considered to be that portion of the main intersecting highways lying outside of the curb lines.

INSTRUCTIONS TO FOREMEN. *General:* 20. If you do not understand these instructions, or how to fill out the forms, ask the person to whom you report to explain matters to you.

21. In filling out the forms, you should write as plainly as possible. If it is possible for you to do it, all work symbols should be shown in printed capital letters. Write everything out in full. This will prevent misunderstandings.

22. Keep the forms in a clean and neat condition. Do not fold them more than is absolutely necessary. Carry the forms in the folder provided for that purpose.

23. Everything you enter on forms must be written in your own handwriting and while you are on the work.

24. Where two words are printed together, such as "Inspector" and "Foreman"; "a.m." and "p.m.,' etc, the word not required should be crossed out.

25. Do not write anything in the columns whose headings are shown in red ink.

26. Send your report forms to the district office at the close of each day's work.

Kind of Work Symbols: 27. If the kind of work symbol is not shown on your route sheets, get the proper symbol for the work from the symbol list. If it is possible to do so before sending in your reports for the day, ask the person to whom you report if you have selected the correct symbol.

Route Sheets: 28. The work must be performed in the order in which it is shown on your daily route sheets, unless the person to whom you report orders you to do otherwise.

29. If it is necessary to do any work not shown on your route sheets, make a record of it on the route sheet.

30. Send route sheets to the district office at the close of work each day. If all of the work shown on the route sheet has not been finished, strike out the unfinished work locations and transfer them to a blank route sheet which should be returned to the office on the following day.

31. For each item of work done, you must give its length and width in feet; and its location in measurements from the curb lines.

32. When you do all of the work shown on the route sheet, sign it with your full name.

Material Issue Orders: 33. When you order materials from the yard or from another foreman, fill out a Material Issue Order in triplicate, and give the district number, the name and location of the storekeeper, or foreman to whom the order is sent, the character of work symbol, the quantity, unit and description of the material ordered and the date and hour that the material was ordered. The duplicate copy of the material issue order must remain in the order book, and the original and triplicate copies must be given to the storekeeper, or foreman, who must write the date and time that the material was issued. The storekeeper, or foreman, must keep the original copy and return the triplicate copy to the driver to whom he issues the material. The driver must turn this copy over to you when he delivers the material and you must write on it the time that the material is received. If you make a mistake in making out a material issue order, all three copies must be marked "void" and the original and triplicate copies sent to the district office. When you have used all of the material issue orders in a book, the book containing duplicate copies of the orders must be returned to the district office. Describe all materials fully; that is, the sizes of crushed stone, pipe, etc, should be mentioned.

Time, Progress and Material Sheets: 34. During each day's work, enter the following information on the form for that date: The kind of work symbols; the kind of street

(city or P. R. T. Co.); the time of the arrival and departure on the job of each workman and team; the location of the work done, shown by the names of the highway, block or intersection or structure; the time spent on each kind of work for each man and team; the length, width and quantity of work peformed; the quantity and character of materials received and used; and the number of hauling trips made. Sign this form and send it to the district office at the close of each day's work. Be certain to write the information for each kind of work in the proper spaces. To help you in this, the several spaces to be filled out for each kind of work are marked with the letters "A" to "H."

Asphalt and Block Pavement Work: 35. Under "granite block," "vitrified block," "asphalt" and "concrete base," enter any work where these materials are used. If

BUREAU OF HIGHWAYS Department of Public Works Philadelphia	ROUTE SHEET FOR MAINTENANCE WORK	DIVISION OF MAINTENANCE (Highways)
		District Number / Date
		Foreman

Location		Permit Number	Class of Work	Distance From				Work Done			Cost	
Block	Specific			N.C.L.	S.C.L.	E.C.L.	W.C.L.	Length Feet	Width Feet	Area Sq. Yds.	Unit	Total
Reverse side for remarks												

Signed (Foreman)	Approved: (Assistant Engineer)	Totals				

Form D

HIGHWAY BLOCK RECORD

Highway From To

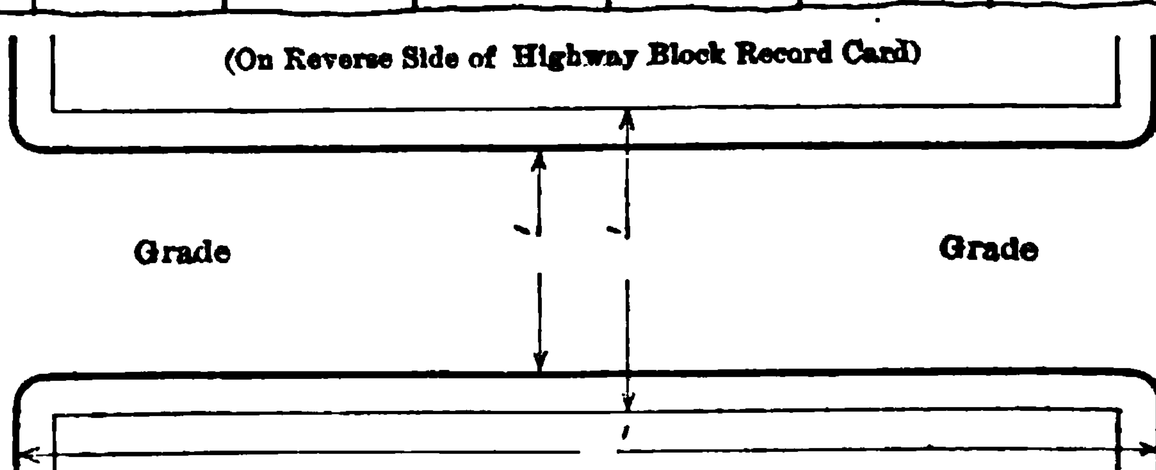
Paving: Surface Base Unit Cost: Surface Base

Paved By Address

Finished Guarantee Period Years. Expires

MAINTENANCE DATA

Year	Yardage Repaved	Total Cost	Unit Cost	Unit Cost Per Year Per Sq. Yd. of Pavement	Yardage Repaired over Cuts	Remarks



Block Area Square Yards

Remarks:

Form E

the sizes of the blocks are unusual, this fact must be stated. If the concrete base is of any mixture other than 1:3:6, a note to this effect must also be made.

Road Work: **36. The words "macadam roads" mean all roads surfaced with crushed stone, whether having a telford or a macadam base; or having a bituminous surface treated or a water-bound surface.**

37. The words "earth roads" mean all other roads, except those surfaced with ashes or cinders, which roads must be included under the heading "cinder roads." If the material is not cinders, then state what kind of material it is.

38. All gutter work, whether new paving or repairing, must be entered under the heading "paved gutters." The cleaning and improvement of gutters on earth roads must be considered as a part of the general maintenance work on that class of road.

39. In the blank space under "cinder roads" must be entered the kind of work done.

40. Characters of work not provided for with printed headings must be entered under the "miscellaneous work" heading.

Sprinkling: **41. When sprinkling is done, the complete routes followed must be entered on a sheet attached to the time, progress and material sheet, and on this sheet each route should be preceded by one of the letters "A" to "H" to properly identify the entries with those on the time, progress and material sheet.**

42. The number of loads of water used on each route must be given.

Measurements: **43. Measure the length of all pavement repairs parallel with the highway on which the repairs are made; and, in the case of highway intersections the length of the repaired area must be considered as being parallel with the highway first mentioned in naming the intersection.**

44. Where it is convenient to measure the distances of repairs from the curb lines of any small intersecting highway, it should be done, and a note should be made on the back of the route sheet. Otherwise measurements must be made from curb lines of main intersecting highways.

The Maryland State Roads Commission's (39) uniform system of compiling the records of all expenditures is shown by the chart of Table I, the explanatory notes which follow, and Table II, which illustrates the method of distribution of expenses to Dec. 31, 1911.

Table I.—Chart Showing Distribution of Expenditures, Maryland State Roads Commission

Cost	Administration and legal	Commission's salaries and expenses.
		Commission's office force, salaries.
		Commission's office expenses.
		Commission's counsel, salaries, fees and expenses.
	Engineering, general	Chief Engineer's salary and expenses.
		Chief Engineer's office employees' salaries.
		Chief Engineer's office expenses.
		Chief Engineer's instruments and repairs.
		Chief Engineer's laboratory investigations.
	Preliminary	Engineers in charge, salary and expenses.
		Survey parties, salary and expenses.
		Office employees', draftsmen, etc, salaries.
		Office expenses, stakes, etc.
	Construction, reconstruction, maintenance	Engineers in charge, salaries and expenses.
		Office employees, salaries.
		Office expenses.
		Inspectors, salaries and expenses.
		Superintendents, salaries and expenses.
		Foremen, labor, teams, etc, pay of advertising.
		Materials consumed, expense for.
		Use of equipment, rental for and repairs.
		Rights-of-way and damages.
		Advertising.
		Miscellaneous.
	Equipment	Expense for.
		Transportation of and establishment.
		Renewals and depreciation.
		Salaries of men in charge of, etc.

Administration and Legal. COMMISSION SALARIES AND EXPENSES. Salaries paid to members of the Commission. Also all expenses of members of the Commission when engaged on the work of the Commission, such as railway fares, team and automobile hire, subsistence and incidental expenses.

COMMISSION, SECRETARY'S AND OFFICE EMPLOYEES' SALARIES. All the salaries of the Secretary of the Commission and of all bookkeepers, clerks, stenographers and office boys in the employ of the Commission in its main office.

COMMISSION, OFFICE EXPENSES. All office expenses of the Commission such as rents, telegrams, telephones, postage, messengers, books, typewriters, adding machines, stationery and office supplies.

COUNSEL'S SALARY, FEES AND EXPENSES. Salary of the Counsel and such fees as are necessary to be paid other attorneys in the legal proceedings of the Commission which, from their nature, cannot be charged direct to a particular road or county. Also the traveling, subsistence and other incidental expenses of counsel when engaged on the business of the Commission.

Engineering, General. ENGINEER'S SALARY AND EXPENSES. Salary of the Chief Engineer and his traveling, subsistence and incidental expenses when engaged on the business of the Commission.

OFFICE EMPLOYEES, EXPENSES. Salaries of the Chief Engineer's Secretary, clerks, stenographers and office boys.

OFFICE EXPENSES. Office expenses of the Chief Engineer, such as rent, telegrams, telephones, postage, messengers, books, typewriters, adding machines, stakes, instruments, stationery and office supplies.

SHOP LABOR AND MATERIAL. Labor and material used in the shop operated under the direction of the Chief Engineer.

TESTS AND INVESTIGATIONS. Cost of the time of chemists, physicists, or others engaged under the direction of the Chief Engineer in conducting tests and investigations together with the cost of the materials used in connection therewith.

Preliminary and Construction. ENGINEER'S SALARIES AND EXPENSES. Salaries and traveling and incidental expenses of all engineers engaged exclusively on Preliminary or Construction work. At present they consist of those of the Construction Engineer, the First and Third Assistant Engineers, and the Chief Draftsman.

ENGINEER INSPECTORS' SALARIES AND EXPENSES. Salaries, subsistence and incidental expenses of all Engineer Inspectors engaged exclusively on Preliminary and Constructive work.

OFFICE EMPLOYEES' SALARIES. Salaries of clerks, stenographers, office boys, etc, employed in the offices of the Construction Engineer, the First Assistant Engineer, and the Third Assistant Engineer.

OFFICE EXPENSES. Office expenses of the Construction and First Assistant Engineers, consisting of telegrams, telephones, books, typewriters, stationery, and office supplies.

Maintenance and Reconstruction. ENGINEERS' SALARIES AND EXPENSES. Salaries and traveling and incidental expenses of Engineers engaged exclusively on this class of work. At present they would consist of those of the Second Assistant Engineer, and vacations of inspectors.

ENGINEER INSPECTORS' SALARIES AND EXPENSES. Salaries and traveling and incidental expenses of all Engineer Inspectors engaged exclusively on Reconstruction and Maintenance work.

OFFICE EMPLOYEES' SALARIES. To this account should be charged the salaries of clerks, stenographers, office boys, etc, employed in the office of the Second Assistant Engineer.

OFFICE EXPENSES. To this account should be charged the office expenses of the Second Assistant Engineer, consisting of telegrams, telephones, books, typewriters, stationery and office supplies.

Preliminary. SURVEY PARTIES. To this account should be charged the salaries and expenses of engineers and their parties in the field, engaged in surveying and locating proposed new roads.

DRAFTSMEN. To this account should be charged the salaries of draftsmen engaged in preparing the plans and drawings for the proposed new roads.

Construction. All construction work should be done under regular contract or force work orders, which should bear distinctive numbers. An account should be opened

Table II.—Distribution of Expenditures, Maryland State Roads Commission

				Percent	
Total expense, $4 422 520.54	Administration and legal, $62 910.51, 1.4%		Commission salaries and expenses	50.33	$31 666.42
			Commission secretary and office employees' salaries	23.41	14 728.05
			Commission office expenses	16.33	10 273.71
			...nses	9.93	66 242.33
	Engineering general, $56 318.72, 1.3%		...s	27.81	15 660.59
				28.62	16 118.02
				37.49	21 116.22
				5.01	2 820.29
				1.07	603.60
	Preliminary and construction, $4 126 911.46, 93.3%	Engineering, $56 056.90, 1.3%	...s	27.96	15 675.81
			...d expenses	38.53	21 596.72
				31.54	17 680.85
				1.97	1 101.52
		Preliminary, $59 907.12, 1.5%		34.06	20 405.63
				65.94	39 501.49
		Construction, $4 010 947.44, 97.2%		6.91	277 157.76
				15.45	619 652.88
			Surfacing	56.10	2 250 318.16
			Bridges and culverts	12.65	507 214.38
			Drains	1.20	48 103.13
			Advertising	0.07	2 976.87
			Inspection	2.44	97 677.18
				0.40	16 242.81
			... and plans	0.03	1 100.00
			Miscellaneous	0.37	14 789.26
			United Railways Company's work	4.38	175 705.11
	Reconstruction and maintenance, $128 949.47, 2.9%	Engineering, $414 293.25, 11.1%		19.07	2 725.21
			...expenses	50.82	7 263.66
				23.93	3 421.05
				6.18	883.33
		Reconstruction, $16 378.92, 12.7%		33.65	5 512.12
			...t	21.46	3 515.02
			Superintendence	32.20	5 274.14
			Inspection	12.69	2 077.64
		Maintenance, $98 277.30, 76.2%	Labor	22.20	21 820.41
			Materials	57.31	56 320.75
			Team hire and use of equipment	13.66	13 419.10
			Superintendence	5.77	5 675.98
			Inspection	1.06	1 041.06
	Equipment, $47 480.88, 1%	Construction	Rental charge for average time at 5% per month equals		14 568.00
		Maintenance	Rental charge for average time at 5% per month equals		596.00
		Reconstruction	Rental charge for average time at 5% per month equals		800.00

for each such price of work, such accounts to be grouped as to funds from which paid and counties in which work is located.

RIGHTS-OF-WAY AND DAMAGES. Cost of land, acquired for right-of-way, expenses of appraisals, and of commissioners or arbitrators in condemnation proceedings, commissions paid for purchases of additional rights-of-way, payments for damages or repairs to abutting property and counsel's fees and expenses when specifically applicable to the cost of acquiring certain right-of-way.

GRADING. Cost of grading, including the cost of operating steam shovels, scrapers and grading outfits, the hire of teams and equipment, a rental for the Commission's equipment used and the cost of miscellaneous tools and supplies used on the work. The cost of grading done under contract should be charged this account from the vouchers in favor of the contractors.

SURFACING. Cost of all labor employed and material used in surfacing, including the cost of operating stone crushers, spreaders, road rollers, sprinklers and oilers, the hire of teams and equipment, a rental for the Commission's equipment used and the cost of miscellaneous tools and supplies used on the work. The cost of surfacing done under contract should be charged this account from the vouchers in favor of the contractors.

BRIDGES AND CULVERTS. Cost of labor employed and material used in construction of bridges and culverts, including the hire of teams and equipment, and the cost of miscellaneous tools and supplies used on the work. The cost of bridging and culverting done under contract should be charged this account from the vouchers in favor of the contractors.

DRAINS. Cost of labor employed and material used in construction of under or V-drains, including the hire of teams and equipment and the cost of tools and supplies used on the work. The cost of drain work done under contract should be charged this account from the vouchers in favor of the contractors.

ADVERTISING. Cost of advertising the terms under which contracts for the work may be let.

INSPECTION. Salaries and expenses of inspectors on the work.

SUPERINTENDENCE. Salaries and expenses of superintendents in charge of work done by the Commission's forces.

FINAL SURVEYS AND ESTIMATES AND PLANS.

Reconstruction. LABOR AND MATERIALS. Cost of labor employed and materials used in reconstruction of roads and turnpikes acquired.

TEAM HIRE AND USE OF EQUIPMENTS. Payments for hire of teams and equipment and a rental for the use of the Commission's equipment on the work. It should include the labor employed and materials used in operating and maintaining the equipment in use.

SUPERINTENDENCE. Salaries and expenses of superintendents and foremen in charge of reconstruction work.

INSPECTION. Salary and expenses of inspectors engaged on work of reconstruction.

Maintenance. LABOR. Cost of labor employed in maintaining existing roads.

MATERIALS. Cost of materials used in the maintenance of existing roads.

TEAM HIRE AND USE FOR EQUIPMENT. Payments for use of teams and equipment in the maintenance of existing roads together with a rental for the use of the Commission's equipment so used.

SUPERINTENDENCE. Salaries and expenses of superintendents and foremen engaged on maintenance work.

INSPECTION.

Equipment. Purchase price of all equipment which may have substantial value after it has been used on any particular piece of work, such as road rollers, crushers, scrapers, graders, sprinklers, horses and wagons, auto trucks, etc. Small tools and other equipment which quickly wear out or become valueless should be charged to the work for which purchased at the time of purchase and upon the completion of such work should be appraised and credited to it. The Commission's equipment should be inventoried and numbered and a proper record kept thereof. Charges for the use of the equipment should be made against the work on which it is employed the credits for which may be carried in a "Depreciation Reserve" account.

Rules for Distribution of General Accounts. The monthly total of the engineering expenses, specifically applicable to Preliminary and Construction work, should be

charged to Construction Preliminary and to Construction in proportion to the total amounts charged direct to those accounts during the month. The monthly total of the engineering expenses specifically applicable to Reconstruction and Maintenance, should be charged to Reconstruction and Maintenance in proportion to the total amounts charged to those accounts during the month. The monthly total of Administration and Legal and of the General Engineering expenses should be charged to Construction-Preliminary, Construction, Reconstruction and Maintenance in proportion to the total amounts charged direct, including the specifically apportioned charges for engineering expenses, to those accounts during the month. Exception: No part of the overhead charges is to be added to the maintenance expenditures made from the allotments of the Motor Vehicle Tax to Counties for maintenance of State Aid roads.

Rules for Segregation of Items of Work Done. GRADING. Under the head of Grading should be included all excavation, including ditch, masonry, culvert and bridge excavations, as well as the excavation covered by the cross-sections and from the borrow pits.

CULVERTS AND BRIDGES. Under the head of Culverts and Bridges should be included all pipes, boxes, as well as culverts and bridges of all kinds used toward the end of disposing the storm water coming to the road from above or from the surface of the adjacent lands.

UNDERDRAINS. Under the head of Underdrains should be included V-drains, blind drains, sumps, as well as the standard underdrains, and such other devices as are installed for the purpose of taking care of the ground, or sub-surface, water.

SURFACING. Under the head of Surfacing should be included, as well as the macadam or actual surfacing prescribed in the specifications under such head, all paved gutters, curbing, concrete or other breakers across the shoulders, gravel, etc, used for the shoulders, when so used particularly and independently of the grading expressly for the purpose of improving the shoulders, and any material such as sand, cinders or stone dust used as a layer between the subgrade and the surfacing proper.

MISCELLANEOUS. Under the head of Miscellaneous will be included only those items which cannot be reasonably placed in one of the foregoing classifications, and under the head of Remarks should be placed an explanation of any miscellaneous item amounting to over $100. Advertising may be placed in the miscellaneous column. Removing and rebuilding fences should be charged to right-of-way when possible. Guard rail for culverts should be charged to culverts and bridges. Guard rail to protect embankments should be charged to grading. Rip rap may be placed in the miscellaneous classification, but if amounting to more than $50, statement should be so made under the head of remarks. Catch basins and inlets, as well as storm water sewers along the road should go under the head of culverts and bridges. Pipes or ditches across private property as outlets to our culverts should be charged to right-of-way whenever practicable.

PRELIMINARY. This covers the work of the Engineering Department in making surveys, plans, calculations, investigations, estimates, specifications, etc, up to the advertising of the work for bids.

CONSTRUCTION. This is the work of the Commission or of its forces in the improvement according to the Preliminary plans, specifications, etc, of a structure, or the building of a structure *de novo*, on a section of a State Road in the State, or State-Aid Road, System.

RECONSTRUCTION. This covers the rehabilitation, serious repair, rebuilding or replacement of old structures on the turnpikes, or State-Aid Roads, taken over by this Commission for maintenance by it.

MAINTENANCE. This covers the work of preventing the deterioration of repaving, up-keeping, of treating with oil, pitch, etc, and generally of keeping in satisfactory condition the roads, and structures on them, under the charge of the Commission.

11. Correspondence Procedure

Purpose. In systematizing the work of a highway department it is very necessary among other matters of a fundamental nature that the correspondence procedure should receive careful consideration. In selecting

a proper procedure the following outlined system in operation in 1917 in the Bureau of Highways and Street Cleaning of Philadelphia is recommended as embodying all of the desirable features existing in the standard systems used by some of the best equipped business organizations and which would be applicable to the situation as presented in a highway department.

The purposes for which this procedure is intended to provide are as follows:

1. The centralization of the responsibility and of the operations of each detail of the correspondence procedure, involving the establishment of a central correspondence receiving, recording, routing and filing division; a central dictation room; and a central transcribing room.

2. The elimination or the reduction to a minimum of the possibility of loss or delay in the handling of correspondence, or of the destruction of the files by fire.

3. The installation of a logical and easily accessible subject classification filing system and of modern filing equipment.

4. The reduction to a minimum of the clerical labor expended in the operation of the correspondence procedure.

General Organization. The operation of the correspondence procedure should be under the general supervision of the chief clerk, to whom should report the chief stenographer and the stenographic force, mail clerks, complaint clerks, file clerks and messengers.

The STENOGRAPHIC FORCE should be segregated in one room to be used exclusively for transcribing. Adjacent to this room should be located the central dictation room, and the correspondence, receiving, recording, routing and filing rooms, and in order to insure privacy and to eliminate interruptions and the consequent loss of time, which is ever present when dictation is given amid the general activities of an office, all of the employees having dictation to give should be required to use the central dictation room. To further facilitate the systematic handling of this work, each correspondent should be assigned a stenographer and a definite period of time in which to dictate. These assignments should constitute a permanent daily schedule and no business other than dictation should be transacted in the dictation room.

The MAIL CLERKS should receive, register, route and dispatch all incoming communications other than service complaints which should be attended to by the complaint clerks. The file clerk should classify and file all correspondence sent to file and fill all requisitions for correspondence to be removed from the files. The messenger should collect copy and mail or distribute all local and outgoing correspondence.

INSTRUCTIONS, FORMS AND EQUIPMENT, as follows, should be provided to insure the systematic operation of the correspondence procedure: (1) Written correspondence procedure instructions; (2) acknowledgment postal card; (3) service complaint forms; (4) service complaint register sheet; (5) a routing direction form stamp; (6) mail register sheet; (7) reference register sheet; (8) schedule of mnemonic filing classification symbols; (9) metal filing and transfer cabinets, durable paper folders and metal-tipped index guides; (10) correspondence requisition; (11) carbon copy sheets, one each of distinctive colors for copies of registered correspondence, correspondence originating in the main office, and tickler copies; (12) tickler filing cabinets; (13) printed form letters; (14) reference report form.

General Operation. See Fig. 7. All employees having to do with the correspondence procedure should be uniformly guided by a set of writ-

ten instructions, which should cover in detail the routine procedure. Incoming communications may be divided into two general classifications as follows: (1) General correspondence or communications other than service complaints; (2) service complaints.

Receiving and Routing General Correspondence. All communications received at the main office, whether they be written, telephonic or verbal, should be transmitted in tangible form to the mail clerk. In the case of any communications where a definite or conclusive answer must be delayed until an investigation has been made, the mail clerk or complaint clerk should immediately forward to the author a postal card acknowledging receipt of the communication and advising that the department will give the matter prompt attention. On each individual incoming communication the mail clerk should stamp the routing direction form and on this direction form should be indicated the assigned serial registration number and the date of the communication's receipt. In order to afford a means of identification should it subsequently become separated, any relative data attached to or accompanying the original or first sheet of a communication should be numbered with the same serial number as is assigned to the first sheet of the communication. The routing direction form indicates in proper sequence the person or persons or the division or office that the communication should be referred to and what disposition is to be made of it. The names of persons regularly receiving routed communications should be indicated simply by agreed symbols consisting of the first one or two letters of their surnames or official designations. The disposition directions also indicate whether the contents of the communication are merely to be noted by the recipient or that a written or verbal report is desired, or that a reply to the author should be sent direct, or prepared for the approval and signature of a higher authority.

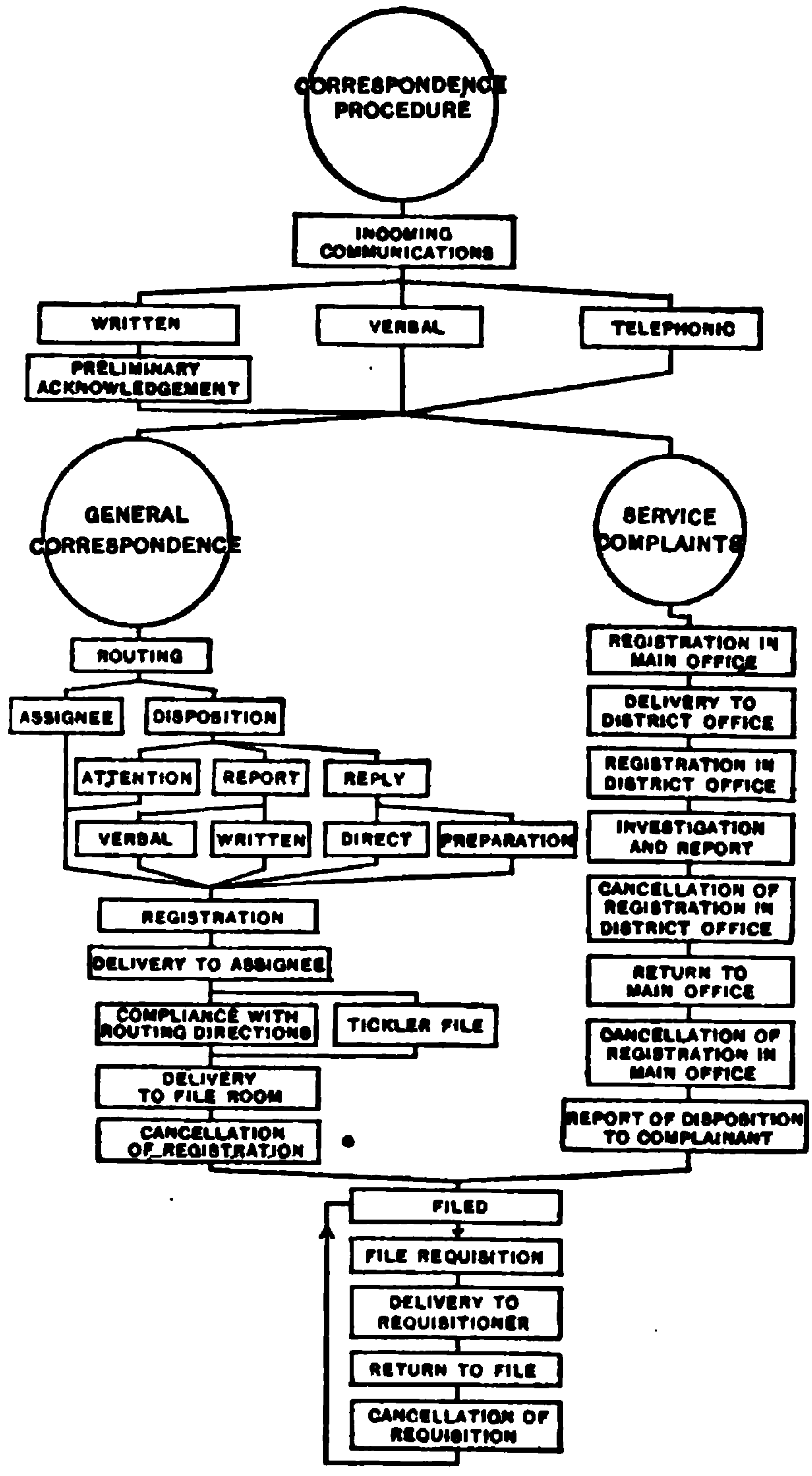


Fig. 7. Correspondence Procedure Administration Chart

After being properly routed the communications should then be arranged in numerical order and recorded upon the mail register sheet, the following data being indicated for each specific communication: The date of receipt; the registration serial number; the name of the author and the subject of the communication; and, the routing directions. This recording should be done in typewriting, the date being dictated

directly by the mail clerk to the typist. The mail register sheets are then filed chronologically in a loose-leaf binder and the communications distributed by a messenger in accordance with the routing directions.

Upon receipt of a registered communication the recipient should indicate in the routing direction form the date of its receipt and later on the date that the communication is subsequently forwarded to either another person or unit of organization or is sent to file. If it is necessary for the original recipient to refer the communication to another person or unit of the organization, the name symbol and the desired disposition should be indicated in ink on the routing direction form. All routing subsequent to the original routing by the mail clerk should be noted in the mail register by the mail clerk thru whose hands must also pass all referred communications. Once each week the mail register sheets for dates exceeding 1 week previous should be checked, and if necessary an investigation made of all entries not closed out by the return to file of the registered communications. If, during this investigation, it is possible to ascertain an anticipated return date, this date should be recorded temporarily in pencil in the mail register. On the 1st and 16th day of each month the mail register sheets upon which all entries are closed out should be removed from the active binder and filed in the inactive binder.

The registering and routing of communications make it possible to locate at any time any specific communication desired, and also place upon a person especially trained in the requirements of the work the responsibility for the intelligent routing and prompt distribution of communications.

Communications routed to the district highway offices should be, immediately upon their receipt, recorded alphabetically according to subject or name of author in the district reference register. In this register there should be indicated for each communication the following data: The serial reference or registration number; the name of the author; the subject of the communication; the date of receipt at the district office; the name of the person to whom referred, and date of such reference. The district reference register sheets should be filed alphabetically in loose-leaf binders and should be checked at frequent intervals, to insure prompt attention and the return to the main office, when necessary, of all correspondence.

Reports and Answering of General Correspondence. Reports on communications forwarded to the district highway offices for investigation should be prepared on report sheets in the handwriting of the person who made the investigation, and for this purpose copying ink or pencil should be used. These reports should contain the serial registration number of the original communication; the date of the investigation and the investigator's report and signature. After being approved by the district assistant engineer, these reports should, if so desired, be copied in a copying book and then forwarded to the main office, accompanied by and attached to the original communication. The entry in the district reference register should be closed out by noting the date of the return of the communication to the main office and the page number of the impression in the copying book.

Wherever practicable PRINTED FORM LETTERS, such as Form F given herewith, should be provided for routine correspondence originating in both the main and district offices, and also for certain inter-department correspondence where the uniform nature of the subject matter and the number of such similar letters make this desirable in the interests of economy and the saving of clerical labor. These letters should be printed in copying ink and should include all of the fixed data and provide blank spaces for the insertion of the variable data. When the routine practice requires the same subject data to be communicated to two or more different agencies the saving of time may be further facilitated by preparing the letters in duplicate, triplicate, etc, in one operation by the use of the carbon paper. The fixed printed form of both the original and duplicate copies of the letter should indicate the agency to which the respective copies are directed, and this should be further emphasized by printing the original copy on white paper and the duplicated copies on tinted papers. Practically all of the routine interdepartment and bureau correspondence may be conducted by means of printed form letters. When the number of letter forms used would not warrant the expense of printing, it is sometimes of advantage to prepare forms on some sort of duplicating machine, such as a mimeograph or hectograph.

DEPARTMENT OF PUBLIC WORKS
BUREAU OF
HIGHWAYS AND STREET CLEANING
ROOM 232, CITY HALL
PHILADELPHIA

WILLIAM H. CONNELL
Chief of Bureau

191....

Subject:—Request for preparation of Paving Contract No......
City Solicitor,
Philadelphia.
Dear Sir:—

Bids were received............191... for paving..........................St. from..............................Street, to.......................Street, with..., authorized by Ordinance of..............; and being low bidder, was awarded the contract.

The total cost of this work will not exceed $..................., and of this amount the cost to the City for paving intersections and in front of unassessable property will not exceed $..........................., to be charged against Item.......... This work must be completed within ....days after date of notice to proceed. The amount of penal bond required at...... percent of contract will be $....................., to be furnished by.............................

Please prepare contract in accordance with existing ordinances and accompanying proposal and specifications.

Yours truly,

APPROVED: Chief of Bureau of Highways.
Ass't Director, Dept. of Public Works.

Form F

CARBON COPIES should be prepared for filing purposes of all correspondence originating in the department, except that correspondence covered by printed form letters. Three colors of paper should be used for this purpose. Letters relative to communications having a serial registration number indicating their origin outside of the main office should be duplicated on orange tinted paper, while duplicates of all letters originating in the main office and therefore having no serial registration number should be prepared on yellow paper. When it is necessary or desirable that a tickler or follow-up be provided, an extra copy should be prepared on pink paper. The serial registration number shall be indicated on all carbon copies of registered correspondence and correspondents should be requested on the original of such letters to refer to this number in answering.

If so desired, in addition to the preparation of carbon copies for filing purposes all outgoing correspondence may be copied in LETTER BOOKS, separate books being used respectively for the various classes of correspondence, such as letters for subordinates in the main highways office; the district highway or division offices; inter-department correspondence; public utilities; contractors; and, miscellaneous which should include all letters not included in the several foregoing classifications.

Filing. For the purposes of public service work the SUBJECT CLASSIFICATION METHOD of correspondence filing is the one most generally used and it is especially adapted for a highway department where the activities, while varied, are also well defined. To facilitate the subject classification of correspondence a schedule of classifications and corresponding mnemonic symbols should be provided. This schedule should also indicate the manner in which the correspondence in each classification is to be filed, whether numerically by registration serial number, or alphabetically by author's name, geographical location, etc. The filing compartments should be arranged in the same sequence as indicated in the schedule of mnemonic symbols. When correspondence is ready for filing this fact should be indicated on the routing direction form and the correspondence should be collected and delivered by the messenger to the file clerk, who determines and indicates thereon the proper filing classification symbol, which symbol should also be recorded in the mail register opposite to the original record of the communication, together with the date upon which the communication is filed.

REMOVAL OF CORRESPONDENCE BY REQUISITIONS. No correspondence should be removed from the files except by the file clerk and then only upon requisition. These requisitions which are prepared in duplicate by the person desiring the issuance of correspondence, should contain the following data: The date of issue; the nature of the desired correspondence; the date of its anticipated return to file; the filing classification symbol; and, the requisitioner's signature. These requisitions should be given to the file clerk in return for the issued correspondence. The original copy of the requisition should be inserted in the folder in the place vacated by the issued correspondence, and the duplicate copy should be retained by the file clerk as a tickler to insure the return to file of the issued correspondence at the time indicated. Upon the return to the file of the issued correspondence, both the original and duplicate copies of the requisition should be surrendered to and destroyed by the individual to whom the correspondence was originally issued.

EQUIPMENT. Vertical steel filing and transfer cabinets, durable paper folders and metal-tipped index guides should be provided; their use ensures the convenient filing of correspondence in a safe and readily accessible manner.

Service Complaints. Service complaints include all communications relative to cases of alleged neglect, or of the unsatisfactory performance of such municipal services as street cleaning or the collection and disposal of ashes, rubbish or garbage. All service complaints received verbally or by telephone should be recorded directly upon a service complaint form. For the purpose of convenient identification, a distinct color of paper should be provided for complaints relating respectively to street cleaning, garbage collection and the collection and disposal of ashes and rubbish. On each of the forms there should be recorded the following data: The serial number and date of the complaint; the location and nature of the conditions complained of; the name and address of the complainant; and the name of the assumed responsible agency. When the complaint is embodied in a written communication it should be attached to the service complaint form and in these cases it is necessary to indicate on the complaint form only sufficient data to properly identify the complaint and to guide the inspector conducting the investigation. All complaints should then be recorded in the service complaint register preferably by a complaint clerk, the following data being indicated for each individual complaint. The serial number and date of the complaint; the name and address of the complainant or the location of the condition complained of; and the date of transmittal to the district office for investigation and report. When the nature of the complaint clearly indicates an omission or neglect on the part of a service contractor, the main office should send notice of the complaint simultaneously to both the district highway office and the contractor assumed to be responsible. Upon its receipt at the district highway office, the complaint should be registered and issued to an inspector for investigation and report. If a service complaint should be originally received at the district highway office instead of at the main highway office, the complaint should be investigated as usual, and in the meantime, the main office should be advised of its existence and a serial number assigned to it. After being investigated and reported upon by the inspector and the findings or recommendations approved by the district assistant engineer, the complaint form should be forwarded to the main office, where the entry in the service complaint register should be closed out by entering the date of the complaint form's return.

Tickler File. One of the principal and best means for heads of departments and divisions to control the performance of periodical functions and inspections, and of insuring that proper attention is given to deferred and prospective duties, is a tickler or follow-up system. The responsibility for operating such a system should in all cases be assigned to some one definite person.

The STYLE OF FILING CABINET best adapted for tickler purposes consists of twelve drawers, one for each month of the year; and each drawer having a sub-division or index pocket for each day of the month. It is also desirable to provide special compartments in which may be filed such data as requests for forthcoming reports or publications, work to be included in the next letting of contracts, specification amendments, etc. These filing compartments should be of such a size as to enable the tickler copies being filed flat.

USE OF TICKLER FILE. For use in the tickler file, a memorandum or a copy of the involved correspondence made on a tickler filing copy sheet should be used. This tickler filing copy should be of a color distinct from that of the sheets used for general

correspondence, preferably pink, and should indicate the date upon which the matter is due for attention, and the name of the person who is to report upon it or to whom it should be referred. These tickler copies should be filed chronologically. Each morning the person in charge of the tickler file should notify those persons against whom are filed ticklers becoming due on that date, of the nature of the matters to receive attention and if possible secure from them the necessary formal reports or other acceptable assurance that the matter will be given proper attention. The tickler copy should not leave the possession of the person in charge of the file, but should be retained in the file as a further check to insure the actual performance of the indicated duty, either on the date first noted, or at a definite future date, if it is not possible to conclude the matter on the date on which it is due.

12. Permits and Licenses

Classification of Permits. In order that the field covered by the issuance of permits coming under the jurisdiction of the Permit Division of a large municipal highway department may be understood in detail, the four following general classifications are given, together with the natures of the privileges and concessions included in each:

1. Use, including the use of highways by electric railway cars, automobiles, motor-trucks, horse-drawn vehicles and barrows and for the transportation of steam-propelled machines, the moving of buildings and other loads of unusual weight or traction requirements.
2. Occupations, including the temporary occupation of highways by stored materials or structures incident to building or other construction work.
3. Encroachments, including the permanent occupation of space within the lines of a highway, either on or below or above the surface, including tunnels, vaults, awnings, marquise, private bridges, overhead pipe or pole, and wire lines, and portions of buildings.
4. Openings, including the opening of highways for the purpose of installing, overhauling or repairing mains, services, sewers, conduits, vaults, car tracks and appurtenances.

Administration of a Permit Division. The first step in the organization of a Permit Division should be the assignment of a supervising engineer to assume full and exclusive control of the division under the direction of the administrative office of the Highway Department. Any necessary modifications should, however, be made to suit the conditions existing in a state, county or township organization. In the case of a state or county department, for example, it would possibly be necessary to issue permits from the district offices, and if desirable this could also be done in a large municipality. This should be followed by the compilation of a record of paved highways under maintenance guarantee, and a complete record of the character of pavement existing on all streets and roads. To facilitate reference, the records of pavements under maintenance guarantee should be typewritten on cards which should be filed in a visible filing cabinet. On each individual card record should be noted all the information required for use as a guide in issuing a permit. The record of pavements not under guarantee may be made in the form of a map indicating by colors the several characters of pavement. To complete the record and also insure that no permit may be issued for the opening or occupation of a highway on which new pavement is about to be laid or is in course of construction, a copy of the contractor's notice to proceed with the work should be sent by the Engineering Division to the Permit Division where it should be placed on file as a temporary ready reference and destroyed upon receipt of the permanent record, prepared at the completion of the work. An adequate

and efficient set of forms, a modern filing system and an effective follow-up or tickler system should also be installed. Any forms or practices not required by existing legislation and for which no good reason can be assigned for their continuance should be discontinued.

The Forms and Filing Devices of a Permit Division should consist of the following:

1. Pavement record cards; upon which are recorded the character of the pavement and other essential data concerning each block of highway pavement under maintenance guarantee.

2. A record or map indicating by colors the earth roads and the character of pavement on each street or road not under maintenance guarantee.

3. Application forms; upon which the prospective permittee prepares a formal application to open or occupy a highway, or to erect an awning.

4. Permit issuance notification forms; originated in duplicate and by means of which the district officers are notified of the issuance of permits and a tickler copy is retained in the Permit Division.

5. Permit registers; to be used by the district officers to maintain a record of the receipt and disposition of permit notification forms.

6. Notice to the division engineer of the failure of the district office to make within a reasonable time a final report on outstanding permits. The use of this form is based upon the assumption that a division engineer may have under his supervision a number of district offices.

7. A set of four loose-leaf binders for each district office, one binder being used respectively for each of the four kinds of permit register sheets; and numerically indexed active file and a highway name indexed inactive file for the filing of permit notification forms in the Permit Division.

Permits for Opening a Highway. The system for the control of permits involving the opening of a highway for the repairing of existing sub-structures, or the installation of service connections or other minor sub-structures should be as follows: The applicant should prepare a formal application (Form G) indicating the name and address of the permittee, the location for which the permit is asked, and the nature of the work to be done under the permit. This application should be presented to a permit clerk who should immediately refer to the record of highway pavements. If no maintenance guarantee exists, or it has expired, and there is no other objection, the

BUREAU OF HIGHWAYS DEPARTMENT OF PUBLIC WORKS PHILADELPHIA	APPLICATION FOR PERMIT TO OPEN HIGHWAY PAVEMENT	APPLICATION NUMBER

INDICATE WITH "X" THE CHARACTER OF PAVEMENT TO BE OPENED	
Asphalt block	
Bituminous macadam	
Cement concrete	
Cobble or rubble	
Earth, cinders, etc	
Sheet-asphalt	
Slag block	
Stone block	
Vitrified block	
Water-bound macadam	
Wood block	

CHIEF, BUREAU OF HIGHWAYS,

SIR:

.... hereby

make application for permit to { break / tunnel } highway

to { install water service pipe / repair water service pipe / install sewer lateral / repair sewer lateral } at.............

....

....Street

Name of Applicant..........................

Address..................................

Form G

application may be approved by the permit clerk and the permit issued. If, however, the guarantee has not expired, the application should at once be referred to the supervising engineer who should consult the data on record relative to the previous notification of abutting property owners of the necessity of installing any sub-surface connections within a certain definite number of days prior to the starting of the construction of the guaranteed pavement. The supervising engineer from his knowledge of the conditions governing each specific case either approves the application or disapproves it for sufficient reasons. In the case of public utility corporations the applicant should file either a release from the guarantor of the pavement stating that the opening to be made will not affect the guarantee, or a certified order upon the guarantor to restore the pavement to its original condition. If the application is approved, upon the payment of the regular charge, if any, for the restoration of the pavement, the permit should be issued and should be valid for a stipulated period of time as indicated thereon.

Permits for the Temporary Occupancy of Highways for storing building materials should be governed by the following procedure during issuance: The applicant should pay the regular stipulated fee to the Permit Division, and after signing his name and address on the duplicate permit retained in that Division, the original permit should be issued to him.

Awning Erection Permits should be issued according to the following procedure: The applicant should fill in and present to the Permit Division an application form. This application should be numbered and sent to the proper district office, where an inspector should be assigned to investigate the conditions existing at the location indicated in the application, and upon the return of the forms, with the approval of the district assistant engineer, the applicant should be notified to pay the regular stipulated fee whereupon the permit should be issued.

Details of Operation During Life of Permit. In detail the permit forms must vary according to the purpose for which they are issued, but in general all should contain a serial number, date and nature of the permit, the name of the permittee, the location for which the permit is issued and period of the permit's validity. At the time of the issuance of permits, the permit clerk should fill out a permit notification form (Form H) in duplicate, on which should be indicated the serial number, the date, the nature of the permit, the name of the permittee, and the location for which the permit is issued.

BUREAU OF HIGHWAYS AND STREET CLEANING DEPARTMENT OF PUBLIC WORKS CITY OF PHILADELPHIA	(THIS NOTICE MUST BE RETURNED TO ROOM 232 CITY HALL) NOTIFICATION OF PERMIT ISSUANCE FOR OCCUPATION OF HIGHWAY BY BUILDING MATERIALS	PERMIT DIVISION	
		Permit No.	
		Permit Date	Date of Promised Completion
		Date of Promised Completion	Div. Engr. Notified

ASSISTANT ENGINEER.................DISTRICT

Under permit issued by this Bureau..

....................................is authorized to occupy the highway at location...with building material for a period of one month from the date of this notice.

REPORT

The permittee has complied with all of the requirements of this permit.

(Note any violations on reverse side.)

Signed....................... Date........... WILLIAM H. CONNELL,

Inspector *Chief of Bureau.*

Approved..

District Assistant Engineer

Form H

The original copies of the permit notification form should be forwarded to the respective assistant engineers of the districts in which the permits apply, and the duplicate copies should be filed in the active permit notification file of the Permit Division, numerically by serial number, under the date on which the original notification is to be reported on and returned from the district office.

Upon the receipt of the permit notification forms at the district offices there should be recorded from them in the proper District Permit Registers the following data: The serial number, the date of issue and receipt, the name of the permittee, the location for which the permit is issued, the date of the permit's expiration and the character of the pavement involved. Four Permit Registers should be maintained, one each for openings in highways, occupation of highways by building materials, erection of awnings and miscellaneous permits, respectively. These registers should be gone over daily, thus obviating the possibility of inspections being omitted or neglected for an unreasonable length of time.

Where in regular practice the pavement restoration is performed either by department forces or under a contract, the district assistant engineer should issue the necessary restoration orders and follow them up to insure that the work is performed within a reasonable time. Those permittees who do not pay the stipulated fees, but who are authorized to restore the pavement themselves, or thru an order given to a contractor, should notify the Highway Department when the repairs are to be made so that inspectors can be assigned to supervise the work. If prior to, or at the time of the expiration of the permit's period of validity, which for example in the case of a pavement opening may be 2 weeks, and 1 month where the highway is occupied by building material, etc, conditions become normal by reason of the restoration of the opened pavement or by the removal of permitted obstructions, etc, the final report on the permit notification form should be endorsed by the inspector and approved by the district assistant engineer, and after the entry in the district Permit Register is closed out by the insertion of the date of the final inspection and the inspector's name it should be returned to the Permit Division.

A report should be made at the end of each month to the Permit Division by the district assistant engineers showing all permits not finally reported on and giving the reasons therefor. The permit clerk should check these reports with the active permit notifications on file, and set back under the proper dates, those on which definite promises are given of future reports or repairs to be made either by a permittee, contractor or department forces. If the repairs are not made as promised, a notice should be sent to the division engineer notifying him to give the matter his personal attention and submit a report to the Permit Division within 5 days, and the permit notification form should be set back that number of days and called to the attention of the division engineer if he fails to make his report within that time.

In cases where the validity of a permit has expired and the necessary restorations have not been made prior to the time at which the monthly reports of overdue permits are forwarded to the Permit Division by the several district offices, the promise to finish should not exceed 5 days, unless there are some exceptional circumstances that will warrant an extension of time. In cases where it is necessary that repairs be made within this stipulated period of 5 days, and the Permit Division has not been notified by the district office that the repairs have been made, the permit clerk should get in telephonic communication with the proper district office and ascertain if the repairs have actually been made, as the district office may not have had sufficient time in which to notify the Permit Division. If such repairs have not been made, the Permit Division should issue a written notice to the proper responsible individual or corporation demanding that repairs be made within 48 hr. A copy of this notice should be sent to the proper district office, and the permit notification should be set back for 3 days. If the repairs are not made within 48 hr, the district assistant engineer should cause the repairs to be made under the general repair contract or by department forces, and render an accounting of the cost of the repairs to the Main Office where arrangements should be made to proceed to collect the amount from the responsible party or the surety. The permit notification form should also be forwarded by the district office at the same time with a proper endorsement of the facts of the case. In all cases the permit clerk should, prior to the return of the original copy, note on the reverse side of the duplicate copy of the permit notification from the various steps taken to have restorations made. Upon the return of the original permit notification forms to the Permit Division, the

duplicate copies should be destroyed, and the original copies should be filed alphabetically by location in the inactive file.

The issuance of permits for encroachments and for the use of the highways for the purpose of transporting loads of unusual character or weight should be based upon an investigation of the conditions prevailing in each specific case.

13. Contract Procedure

Purpose. If the actual physical work of highway construction and maintenance is to proceed in an orderly manner, it is necessary that the office procedure relating to the advertisement of proposals and the preparation of contracts should be thoroly systematized. A modern system of contract procedure should have the following purposes in view:

1. The establishment of a complete, concise, flexible and easily interpreted progress record of all work performed by contract, covering in detail and in orderly sequence all the events from the authorization of the work to its physical completion.
2. The provision of data relative to physical, legal and financial conditions by which may be determined the proper time for advertising for bids and for placing work under contract.
3. The installation of office equipment and procedure in which would be required a minimum of engineering and clerical labor in the operations preliminary to the beginning of the physical construction work.
4. The centralization of the control of operations, procedures and conditions having to do with the advertisement of proposals, the preparation of contracts and the order in which the work is to proceed.
5. The provision of data from which any desired character of report concerning contract work could be readily compiled.

Classification of Contracts. With reference to their period of effectiveness, contracts may be divided into two general classifications, namely, annual contracts and job contracts. The annual contracts remain effective only during the indicated calendar year, while job contracts remain in force until the provisions of the contract are fulfilled and accepted. In general, job contracts usually include highway and special construction and maintenance work, while annual contracts include service work such as street cleaning, the collection and disposal of ashes, rubbish and garbage, sprinkling, team hire, etc. While all contracts necessarily follow the same fundamental procedure, the several details of the procedure vary according to the needs of the individual contract. The detailed procedure for highway construction contracts, however, covers all of the possible details for all kinds of contracts, and in view of this fact the description of the contract procedure will be confined to the details applicable to highway construction. For contracts of a nature requiring the use of a lesser number of procedure details, the identity of the several details actually required will be obvious.

Philadelphia Bureau of Highways Contract Procedure. The details of contract procedure as employed in 1917 while the author was Chief of the Bureau of Highways and Street Cleaning of Philadelphia are as follows:

Operating Equipment. To provide for the efficient operation of the contract procedure, the following forms, filing devices and instructions were provided: (1) Contract record sheets, one each of distinctive colors for grading, paving, repaving, surfacing, resurfacing and miscellaneous contracts respectively; (2) schedule of bid forms, one each of distinctive colors for the records of the Bureau of Highways, the Department of Public Works and the City Controller, respectively; (3) certified check and contract award record forms, of distinctive colors, two for the records of the Bureau of High-

ways and one for the records of the Department of Public Works respectively; (4) contract ledger forms, (5) daily progress report postal cards; (6) inspectors' contract work certification; (7) printed form letters for every letter of a fixed form comprising part of the contract procedure; (8) written instructions explaining in detail the operation of the contract procedure; (9) suitable filing cabinets, indexes and loose-leaf binders.

Arrangement of the Contract Record Files. The contract record files, one of which is maintained for the work under the supervision of each of the two division engineers are arbitrarily divided into several logical sub-divisions with the idea that a contract record shall be progressed thru the several successive sub-divisional units of the file as rapidly as the governing conditions would warrant, and from the position currently occupied by the record in any one of the several sub-divisions, could be based the intelligent administration of the subsequent operations of the procedure. The several sub-divisions of the procedure are as follows:

1. AUTHORIZED. In this sub-division the contract procedure has its origin, a record being prepared for each parcel of work immediately after its authorization by ordinance of City Councils. The records in this division are further sub-divided according to the character of the work authorized, as follows: (1) Grading, (2) Paving, (3) Repaving, (4) Surfacing, (5) Resurfacing, (6) Miscellaneous.

2. PROPOSAL ADVERTISEMENT PREPARED. In this subdivision is included the work for which drawings, specifications and proposal forms have been prepared, and will be included in the next advertisement.

3. UNDER CONTRACT. In this sub-division is included any of the work in the several following stages of the procedure: (1) Proposals advertised, (2) contract awarded, (3) contract ordered executed, (4) contract executed, (5) notice issued to contractor to proceed with the work.

4. FINISHED. This sub-division includes all the work that has been physically finished. The records in this division are filed according to the year in which the work is finished.

5. TO BE REJECTED. In this sub-division is included the work for which bids are in course of rejection or the contract is in process of annulment.

6. INACTIVE. This sub-division constitutes the final disposition of records which have been superseded by revised records by reason of the passage of modifying authorization ordinances; the rejection of bids, or the annulment of contracts.

The Origination of the Contract Record. Upon the receipt of a certified copy of the authorizing ordinance, a comparison is made of this ordinance with previous ordinances and any conflictions discovered are noted for adjustment, after which a contract record sheet for the indicated character of work (Form I) is originated and the following data supplied: The name of the highway and the limits of the proposed work; the ordinance date; the character of the existing, if any, and of the authorized pavement; and the numbers of the highway division and district, the survey district and the ward in which the proposed work is located. There is then determined the status of the several following legal and physical conditions. For all classes of highway construction, the Bureau of Surveys is requested to certify to the legal width of the highway; to its being on the city plan and legally opened; and also to the status of any existing or proposed sewers, sewer laterals, manholes and inlets. For paving work only the Department of Revision of Taxes is requested to indicate the tax rate applying to properties abutting on the length of highway involved. The reports submitted in answer to these requests are recorded on the contract record.

DRAWINGS AND ESTIMATES. If the drawings and estimates for the proposed work are not already on file, a set of four copies is ordered from the Bureau of Surveys. Upon the receipt of the drawings and estimates a serial filing number is assigned to two of the sets, and is also recorded on the corresponding contract record. The serial-numbered set is folded or rolled to a standard size and filed numerically. Two sets of the drawings and estimates are forwarded to the district assistant engineer, one copy being intended for a district office record and the other copy being for subsequent issue to the inspector assigned to the supervision of the work.

Conditions Governing Advertisement. The availability for advertising of proposals for performing miscellaneous work and supplying materials and services is governed by the status of conditions especially applicable to each specified situation. In general,

ENGINEERING CONTRACT RECORD

DIVISION		ENGINEERING CONTRACT RECORD		CLASSIFICATION OF WORK	INDEX
DIST. HIGHWAY		FROM	TO	PAVEMENT / EXISTING / PROPOSED	
DIST. SURVEY		CONTRACTOR NAME	ADDRESS	SURFACE	
WARD		SUB-CONTRACTOR NAME	ADDRESS	GUTTERS / TRACKS / BASE	

WIDTH ROADWAY		DAYS ALLOWED		WORK STARTED	WORK FINISHED	DELAY		PENALTY		DRAWING NO.	
WIDTH FOOTWAY		YEARS GUARANTEED				DAYS		DAYS		CONTRACT NO.	
TOTAL		PAVEMENT LENGTH								WATER-ACCESS NOTICE	

ORDINANCE	ON CITY PLAN	LEGALLY OPENED	CITY TAX RATE	ADVERTISED	BIDS RECEIVED	AWARDED	ORDERED	EXECUTED	APPROVED	NOTICE TO PROCEED
GRADING	SEWER	LATERALS	WATER	LIGHTING	CURBING	GAS				

ITEMS	EST'D QUANT'S	UNIT PRICE BID	ESTIMATED COST	ACTUAL QUANT'S	ACTUAL COST	PROVISIONAL REPORTS
						ON CITY PLAN
						LEGALLY OPENED
						TAX RATE
						GRADING
						SEWER:
						LATERALS:
						WATER:
						LIGHTING:
						CURBING: NOTICES EXPIRE
APPROPRIATION ITEM	TOTAL AMOUNT BID			COST TOTAL		GAS:
AMOUNT CERTIFIED CHECK	AMOUNT PLACED ON CONTRACT: TOTAL			CITY		
AMOUNT PENAL BOND	CITY			ASSESSABLE		
	ASSESSABLE			FINISHED DURING YEAR		

Form I

the principal governing factors are, a need for the work, materials or service and the existence of the necessary funds with which to pay therefor. Before a parcel of highway construction work is considered as being available for advertising it is necessary that there should be a demand for the work and that no conditions should exist that would interfere with or prevent the prompt physical prosecution of the work, and, therefore, the status of the following governing conditions should be as indicated in Table III.

Table III

Governing Conditions	Character of Work					
	Grading	City Street			Country Road	
		Paving	Re-paving	Re-surfacing	Sur-facing	Re-surfacing
Authorizing ordinance	Yes	Yes	Yes or No	Yes or No	Yes or No	Yes or No
On city plan	Yes	Yes	Yes	Yes	Yes	Yes
Legally opened	Yes	Yes	Yes	Yes	Yes	Yes
City tax rate	No	Yes	No	No	No	No
At confirmed grade	No	Yes	Yes	Yes	Desirable	Desirable
Sewer constructed	No	Yes	Yes	Desirable	Desirable	Desirable
Plan and estimate	Yes	Yes	Yes	Yes	Yes	Yes
Necessity for work based upon an investigation	Yes	Yes	Yes	Yes	Yes	Yes
Funds available	Yes	Yes	Yes	Yes	Yes	Yes

Yes indicates an absolute necessity that conditions must exist as indicated.

No indicates that it is not necessary that indicated conditions exist.

Yes or No indicates that the existence of the necessity is dependent upon the specific provisions of ordinance appropriating the funds.

Desirable indicates a desirability, but not an absolute necessity, that indicated conditions must exist.

Preparation and Advertisement of Proposals. To insure the efficient operation of the procedure for the preparation and advertisement of proposals for highway work the following forms, equipment and methods were provided:

1. Proposal estimate forms; one distinctive form for each of the four general classifications of highway construction work, each form containing all of the fixed data likely to be used and providing spaces for the insertion of the necessary variable data.

2. Schedule of standard proposal item terms; which provides a complete and logically arranged classified summary of all of the fixed and variable standard terms likely to be used in the preparation of proposals for highway construction work.

3. Proposal or bid forms; one distinctive form for each of three classes of proposals. Two of the proposal or bid forms also contain schedules of fixed prices for every character of contingent work likely to be encountered.

4. Advertised work estimate forms; on which is indicated the limits, quantity and estimated cost of all work proposed to be advertised.

5. Advertised work schedules; which indicate the character and geographical limits of each parcel of work advertised and are issued to prospective bidders to serve as a guide in their pre-inspection of the sites of the proposed work.

6. Proposal envelopes; which are issued to prospective bidders for the purpose of enclosing in them their proposals.

7. Report of low bidders and prices; which facilitates the preparation of reports to the Chief of the Bureau and the press.

8. Specimen sets of the proposal forms, specifications and drawings for each parcel of advertised work; all of which are filed in convenient, readily accessible and properly indexed files for the inspection and information of prospective bidders.

9. Special filing cabinet; in which proposals awaiting distribution to prospective bidders are filed in a readily accessible manner and are properly indexed according to the letting date and schedule letter.

10. Improved method of proposal form distribution by which each prospective bidder is furnished with a complete set of proposal forms for each schedule applied for.

11. A hectograph duplicating device by which the propcsal forms are duplicated, thereby dispensing with the handwriting or typewriting of proposals and subsequently checking them for accuracy.

Preparation of the Proposal Estimate. As soon as the several governing conditions become favorable, the original office copy of the proposal is prepared in ink handwriting on a proposal estimate by the division engineer and checked by his assistant or vice versa. The four kinds of proposal estimate forms were intended to be used as follows:

Form Number	Character of Work to be Used for		
1-A	Grading		
1-B	Paving with		Asphalt Vitrified block Granite block Wood block
1-C	Repaving Resurfacing	with	Asphalt Vitrified block Granite block Wood block
1-D	Surfacing Resurfacing	with	Concrete Water-bound macadam Bituminous material

In general, on each of these forms is recorded the following data: Division (number); location, street, (name) from, (name) to, (name); letting date, (date); certified check, (amount); days allowed for completion of work, (number); estimate of work to be performed, (quantity and character); notes and special requirement, (stated explicitly and briefly, if any). Any printed data on the proposal estimate forms that it is not desired to have appear on the proposal forms is stricken out.

Location of Proposed Work. The location is expressed in a concise manner and entered on the contract records. Numbered streets are indicated by numerals. The highway name need not, however, be followed by street, avenue, road, etc, except where such a designation is absolutely required to distinguish the highway from another having a similar proper name. Numbered street designations should be followed by the suffix st., nd., rd., or th., as may be required. When a highway is bounded by two numbered streets, the lower should precede the higher number. When two or more highways are grouped into one proposal, the named streets should be arranged alphabetically, followed by the numbered streets arranged numerically.

Letting Date. The date of the letting is set for a date at least 11 days after the date of the first insertion of the advertisement in the newspapers. Except where absolutely necessary, lettings do not take place on a Mon. or Sat.

Certified Check. The amount of the certified check is made equal to 2.5% of the estimated cost of the proposed work, and should always be expressed in the nearest round figure which is a multiple of $5. For estimating purposes the figures given in the schedule of fixed prices for contingent work should be used.

Time Allowed for the Completion of Work. In fixing the period of time allowed for the completion of a parcel of work, careful consideration is given to the desirable or necessary speed for the prosecution of the work as governed by actual necessities and its influence upon the probable cost. In grading, especially where rock is to be excavated, or it is permissible to use ash filling and there is no necessity for hurrying the work, it is generally possible to obtain lower prices by lengthening the time limit.

In every instance a fair number of consecutive working days is allowed based upon the following considerations:

1. The period of time within which it is necessary that the work be finished as governed by the dependence of proposed subsequent work and of the necessities of public convenience.

2. The probable influence of the period of time allowed upon the cost of the work.

3. The physical possibilities of performing the work, such as the availability of materials and equipment; the conditions under which the work must be prosecuted;

and the average contractor's probable economical capacity to perform the respective classes of work.

4. The predominance of any specific class of work that would exclusively influence the time required for the performance of the entire parcel of work.

5. The study of plotted curves or other compiled data relative to the average quantities of work performed and the time allowance on previously performed work of a similar character.

For the purpose of definition, the use of such terms as week, month, or year are omitted in favor of the uniform unit of consecutive working day, which includes all days upon which the contractor may properly be expected to, or upon which it may be physically possible to work and excludes Sundays, legal holidays and such other days during which the weather conditions make it inadvisable or impossible to perform work. For extensive operations, such as boulevard construction and park development, it is absolutely necessary that very careful consideration be given to all of the known or probable governing conditions. On straight highway construction work, such as grading and pavement construction, the determination of proper time allowances presents a less complicated problem and may to a considerable extent be based largely upon approximate average values of plant output and the economical number of gangs and men per gang and equipment for hauling obtaining on previously performed work. The notice to the contractor to proceed with the work should allow him sufficient time to assemble his plant before the time is counted against his contract. Ten days is considered to be ample time to allow in which to assemble the equipment, and deliver the materials and start actual work, in the case of ordinary grading and pavement contracts, but it would not be sufficient time in extensive operations, where considerable plant equipment is required. On all work except grading a further allowance of 5 days per entire job is made in the total time allowed to compensate for the time required in the changing of equipment and gangs, cleaning up, etc.

Grading. The general classification of grading may be sub-divided into the distinctive items of earth excavation, rock excavation and filling. The economical limit for performing work by hand is governed by a number of conditions and will probably vary between 5 000 and 15 000 cu yd to meet these conditions. In every case the advisability of performing the earth excavation by hand or by shovel should receive careful consideration. If the shovel method is determined upon, the average depth of the cut and the number of shovels to be operated should also be considered. In connection with rock excavation, the character of the rock and the possibility of the employment of light or heavy blasting should be considered. With respect to filling, the availability of the filling materials should be known with a reasonable degree of certainty. Easily available material may be considered to be easily transported material located within 1 mile or less of the work, or clean ashes being collected from the neighboring territory. Based upon the foregoing considerations and the minimum output of a single plant equipment of average capacity for the class of work and the average number of workmen employed on a job by a contractor conducting several similar operations simultaneously, the following approximate average values are given:

Table IV.—Daily Grading Capacities

Nature of Work		Average Depth in Ft	Cu Yd Allowed per Day
Earth excavation	Hand method	Any	100
	Shovel method	5	250 per shovel
		7	350 per shovel
		9	450 per shovel
Rock excavation, any method		Less than 5	90
		5 and less than 10	100
		10 and over	105
Filling	Material easily available	Any	175
	Material not easily available	Any	125

Pavement Construction. The principal governing factors in the case of pavement construction are the time required for the construction and setting of the cement-concrete base and the setting of the grouted block joints. Consideration must also be

given to the necessity for changing the several types of equipment necessary for the performance of successive stages of the work. It should also be assumed that on work having an area of approximately 8000 sq yd or less, the construction of the surface course will not proceed until the entire concrete base has set. Considering these conditions and assuming 1000 sq yd as a unit area, the following approximate values are used as a basis for tentative calculations:

Table V.—Time Allowances for Initial Thousand Square Yards of Indicated Operations

Nature of Work	Days Allowed
1. PREPARATORY WORK.	
Earth subgrading and rolling on original work	2
Removal of existing water-bound or bituminous macadam pavement including broken stone or telford base, subgrading and rolling	4
Removal of existing sheet-asphalt or block pavement, including broken stone, bituminous or gravel base, subgrading and rolling	3
Removal of existing sheet-asphalt or block pavement from a concrete base	1
Preparation (cleaning, scarifying and shaping) of existing water-bound macadam for resurfacing	1
2. BASE COURSE CONSTRUCTION.	
Cement-concrete, 4, 5 or 6-in base course	3
Broken stone, 3 or 5-in base course	2
Telford, 8-in base course	3
3. SURFACE AND BINDER OR CUSHION COURSE CONSTRUCTION.	
Sheet-asphalt, 2-in surface and 1-in binder courses	2
Asphalt paint coat application and drying	1
Bituminous, 2-in surface course	2
Granite block surface and 1½-in sand cushion courses, including grouted or bituminous joint filling	5
Vitrified block surface and 1-in sand cushion courses, including grouted or bituminous joint filling	3
Wood block surface and 1-in mortar cushion courses, including sand joint filling	2
Water-bound macadam, 3 or 4-in surface course	2
4. SETTING OF WORK.	
Setting of cement-concrete base course at least	3
Setting of grouted joints in granite block pavement	7
Setting of grouted joints in vitrified block pavement	7
Setting of mortar cushion in wood block pavement	2

By interpolating these elemental time allowance values, it is possible to readily determine the proper total time allowance for the initial unit of a 1000 sq yd of any classification or character of work as based upon what may be considered fair average daily performances, using one concrete mixer and single equipment thruout.

In the following schedule are enumerated for convenience of reference the several classifications and characters of work most generally encountered in general highway construction.

As a general rule, it will not be necessary to allow extra time for the performance of the minor items or miscellaneous contingent work as this work is generally done simultaneously with the performance of the principal items of the work. When the area of work exceeds 1000 sq yd the full time as indicated in Table V for each successive process or operation should be allowed for each additional 1000 sq yd or fraction thereof, except the time allowed for the setting of cement-concrete and grout joints and for the changing of equipment, etc, should be included but once. If it is necessary or desirable that two or more plants be operated, then the total area of the work should be divided by the proposed number of plants and the time allowed for the entire contract should be based only upon the quantity of work to be performed in conjunction with one plant, as each additional plant will be assumed to operate simultaneously and at the same rate of progress. In cases where street railway tracks exist, or it is required to maintain the highway partially open to traffic, and it is, therefore, necessary that the pavement be constructed in two or more separate runs, extra time should be allowed to compensate for these unusual conditions. In general where there are any considerations that might mitigate against the performance of the

work within the time fixed for the several classes of work in the foregoing schedule, an arbitrary number of extra days, based on the judgment of the engineer should be added to the time limit. The time limit, except where there are other more important considerations, should in all cases be based largely on the average contractor's economical time limit, and this will vary in different localities. After the total time to be allowed is finally determined upon, if the number of days allowed is not a number divisible by five it is desirable as a matter of policy to express this number of days in the nearest higher round number of days which is a multiple of five.

Table VI.—Time Allowances for Initial and Additional Thousands of Square Yards of Indicated Pavement Constructions

Classification and Character of Work		Days Allowed per Unit of a 1000 Sq Yd	
		Initial	Additional
1. Paving or New Permanent Pavement.			
a. Original permanent construction on unimproved and newly graded highways:			
Sheet-asphalt	Base, binder or cushion and surface courses	15	7
Granite block		28	10
Vitrified block		23	8
Wood block		17	7
b. Displacing existing macadam pavement:			
Sheet-asphalt	Base, binder or cushion and surface courses	17	9
Granite block		30	12
Vitrified block		25	10
Wood block		19	9
2. Repaving or Replacement of Permanent Pavement.			
Displacing existing permanent pavements not on a concrete base with permanent pavements having a concrete base:			
Sheet-asphalt	Base, binder or cushion and surface courses	16	8
Granite block		29	11
Vitrified block		24	9
Wood block		18	8
3. Surfacing or New Semi-Permanent Pavement.			
Original semi-permanent construction on unimproved and newly graded roads:			
Water-bound macadam with broken stone base	Base and surface courses	11	6
Water-bound macadam with telford base		12	7
Bituminous macadam with broken stone base		11	6
Bituminous macadam with cement-concrete base		13	5
4. Resurfacing or Restoration Work.			
a. Replacing existing semi-permanent or macadam pavements:			
Water-bound macadam on existing base	Surface course base and surface course.	8	3
Bituminous macadam on existing base		8	3
Bituminous macadam including cement-concrete base		14	6
b. Replacing surfaces of existing permanent pavements on existing cement-concrete base:			
Sheet-asphalt	Binder or cushion and surface courses	10	5
Granite block		23	18
Vitrified block		18	13
Wood block		12	7
Bituminous macadam		10	5

ESTIMATE OF WORK TO BE PERFORMED. All estimate of quantity items are expressed in the manner and in the terms indicated in the schedule of standard proposal item terms. The proposal estimate forms each contain a complete list of such items as are likely to be included in the character of work covered by that specific proposal estimate form. All fixed data is printed on the form, while all variable data has been omitted and blank spaces provided for the insertion of the required standard terms. Preceding each item on the proposal estimate forms are index numerals which indicate where, in the schedule of proposal item terms, the standard variable terms may be found. These standard variable terms are indicated on the schedule or proposal item terms in capital type and are enclosed in parentheses.

NOTES AND SPECIAL REQUIREMENTS. All proposal data is clearly and briefly expressed but is not abbreviated. When payment is to be made from an anticipated appropriation, the following provision is used. This work is advertised subject to future appropriation by Councils. When it is obvious or probable that excess grading may be required the following provision is used: The cost of all grading that may be required in connection with this work shall be included in the price bid for paving, or other work as indicated.

Preparation of the Original Proposal or Bid Forms. All proposal or bid forms are typewritten in hectograph ink. The data shown on the proposal estimate forms is transcribed to the proposal forms exactly as indicated. If any of the data is obviously or apparently incorrect, the matter is reported to the person who originated it. All deviations from the standard specifications and any special requirements are noted on the proposal estimate forms and approved by the division engineer. If these notes are so extensive that their indication on the proposal or bid form would be impracticable, and it is therefore necessary to adapt or revise the existing standard specifications to meet the requirements of the prospective work, the following clause is entered on the proposal or bid form following the estimate of quantities: Work under this contract is to be performed in accordance with the standard specifications, including corrections as noted, of the Bureau of Highways for (year) marked Specifications for the letting of (date). It is further understood and agreed that this proposal becomes a part of said specifications and further that if any conflict exists between this proposal form and the specifications, the terms of the proposal form shall govern.

The specific kind of proposal or bid forms used for any parcel of work is governed by the character of work as follows: Grading streets or roads, paving city streets, repaving or resurfacing city streets, surfacing or resurfacing country roads, other miscellaneous work, material or service. Whenever possible to do so, all the data is written on the first page of the proposal or bid form so that the hectographed copies may be prepared in one operation.

PREPARATION OF THE HECTOGRAPHED COPIES OF THE PROPOSAL OR BID FORMS. The number of hectographed copies of the proposal or bid form for each specific parcel of work to be prepared is governed by the probable demands of prospective bidders and the needs of the contract procedure after the contract is awarded.

PREPARATION OF THE COST OF WORK ESTIMATE. When the quantity of work to be advertised is definitely determined upon, a report is prepared, giving separately for each division the following data: Character of work, classification of work and character of materials; location of street, name, from .... to ......; quantity, square yards of pavement or cubic yards of grading; estimated cost, lump sum figures for the total cost and the cost to the city for each classification and character of work. These reports are compared with the appropriation ledger to insure the existence of the necessary funds and are finally approved by the Chief Engineer as to the quantity and character of work to be advertised.

CHECKING. The checking is carefully and thoroly done and any necessary alterations made in red ink, and the original data stricken out but not erased. It is especially important that the data shown on the proposal estimate form be absolutely accurate and expressed according to the standard methods and terms before being transferred by typewriting to the proposal or bid forms. The typewritten copy of the proposal or bid form is carefully checked with the original handwritten copy of the proposal estimate form. The responsibility for the accuracy of this final checking should be centered in one person. Spaces are provided on the proposal estimate form for the dates and initials of those persons preparing, checking and typewriting the forms. This data is supplied so that the responsibility for errors can be properly placed.

Preparation of the Advertisement Schedule. For each letting there is prepared an advertisement schedule in which each classification of work and character of pavement material or service is included in a separate lettered schedule arranged alphabetically. The standard arrangement is as indicated in the following specimen schedule, but when some of the enumerated classes of work are missing, only a sufficient series of letters, beginning with A, is used to indicate the schedules: Work advertised, date; bids to be received, date; drawing number, street, and location for each of the following schedules, A, grading, B, sheet-asphalt paving, C, vitrified block paving, D, granite block paving, E, wood block paving, F, sheet-asphalt repaving, G, vitrified block repaving, H, granite block repaving, I, wood block repaving, J, sheet-asphalt resurfacing, K, vitrified block resurfacing, L, country road surfacing, M, country road resurfacing, N, etc, other miscellaneous classes of work, materials or service. Of each advertisement schedule a sufficient number of copies should be hectographed to satisfy the requirements of the prospective bidders and the contract procedure.

Advertisement of Proposals. Proposals are regularly advertised three times in five local daily newspapers, one of which remains the fixed advertising medium for a period of 6 months. It is usually arranged that collectively advertisements appear in a morning newspaper, an evening newspaper and newspapers printed in German, Italian and Hebrew. When proposals for extensive work are advertised, and it is considered advisable to do so, the proposals accompanied by an estimate of the principal items of the work are published in several of the leading engineering journals. When the nature of the work or service included in any contract is such as to require, before bidding, an extensive study of the requirements of the proposed work, or to necessitate the formulation of plans on the part of the bidder, for the provision or establishment of an extensive plant or organization, a proportionately longer period of time is allowed to elapse between the initial advertisement and the submission of the proposals otherwise the time allowed varies between 10 and 15 days. Immediately after the work has been advertised there are noted on the contract record the date of the advertisement's first appearance in the newspapers and the date of the letting.

Distribution of the Proposal Forms. Complete sets of the proposal or bid forms for each schedule are enclosed in proposal envelopes which are stamped: Bureau of Highways, Schedule, (letter); Date of Letting (date).

A set of specifications for the work covered by the schedules is also enclosed. The number of sets of proposal forms to be prepared varies with the demands of the prospective bidders.

A specially designed filing cabinet has been provided in which the proposal forms enclosed in a schedule-lettered proposal submission envelope are filed according to the date of the letting and the schedule letter. Copies of the schedule of advertised work are distributed gratis to all prospective bidders. A complete set of specifications and proposal forms, properly indexed and bound respectively in separate loose-leaf binders, and a complete set of plans of the proposed work are placed at the disposal of the prospective bidders for their inspection and information. No charge is made for the proposal form, but a charge of 50 cents a copy is made for each set of printed specifications necessary to cover the class of work indicated on the proposal forms. Since the entire field of highway construction is covered in three sets of printed specifications, the maximum charge that will be made at any one time will likely not exceed $1.50, irrespective of the number of proposal forms issued.

Installation of Sub-Surface and Surface Structures. Immediately after the advertisement of the work, copies of the advertisement schedule indicating the characters and locations of the advertised work are prepared and issued to prospective bidders; the division engineers; the district assistant engineers; the contract record clerks; the district surveyors; the chief clerks of both the select and common branches of City Councils; and the Department of Law. Copies of these lists are also sent to the several municipal bureaus and public utilities, whose structures usually occupy highways, accompanied by a statement that the indicated work is about to be performed and requesting a prompt report of the status of existing and prospective conditions relating to surface and underground structures. This procedure insures the construction and repair, ahead of the construction of pavement, of all necessary structures, including sewers, sewer laterals, manholes and inlets, gas and water mains and services, electrical and telephone conduits and services, street lighting and street railway tracks, and any other street structures.

In response to these notifications the municipal bureau and public utilities will certify either that all necessary work has been finished and thereby release the street in so far as their requirements are concerned, or submit a statement of contemplated work, together with the period of time estimated for its completion. Releases are considered as final reports for the conditions reported on and all other reports are considered as merely provisional, but both classes of reports are recorded on the contract record in order to provide an up-to-date summary of the exact status of the sub-surface and surface structure situation. On the first of each month, in cases where a final report or release has not been received, a tickler statement is sent to each of the several municipal bureaus and public utilities showing the streets for which their respective releases have been requested but not received.

Simultaneously with the advertisement of all work except grading, the district assistant engineer in whose district the proposed work prevails is also requested to report upon the condition of the curbing. Where the installation or resetting of curbing is required the district assistant engineer serves on the tenant of the abutting property a notice requiring that the work, such as is indicated, be finished within 30 days. If at the expiration of 30 days the necessary work has not been done a further notice, demanding that the work be done within 48 hr is served, which, if unattended to, is followed by the issuance of an order on the contractor, having the annual curbing work contract, to do the necessary work and assess the cost against the abutting property owner. The district assistant engineer also serves on all tenants of property abutting on a street on which pavement is to be laid a formal notice to install any necessary sewer laterals or water, gas or electric services or other underground connections within 20 days. The district assistant engineer then submits to the main office a report showing the status of the curbing and also advises of the existence of any condition that would make it necessary to delay the physical prosecution of the highway construction work.

Submission of Proposals. A central locked proposal receptacle has been provided and placed in a location where it is at all times in view of the bidders and where the depositing of proposals cannot be observed. After 12 o'clock noon of the day of the letting, the proposal receptacle is publicly opened and the bids read aloud and also written on blackboards which are exhibited for the several succeeding days for the information of the public.

Contract Ledger. After bids are received there is also originated a contract ledger sheet. In addition to the principal items of information, there are also indicated on this form the dates and serial numbers of all estimates of finished work; the dates, warrant serial numbers and amounts of payments; the dates and amounts of any plus or minus adjustments; the unexpended balance of funds allotted to the contract; the date, percentage and amount of any cash deposit; and the dates of the release of the cash deposit and security bond.

Depending upon the status of the contract, the contract ledger forms are sub-divided into four separate divisions each of which is filed in separate binders as follows: (1) Bids received and contracts not yet awarded; (2) contracts awarded; (3) work finished and under maintenance guarantee; (4) work finished and not under maintenance guarantee.

Schedule of Bids. After the opening of the bids and the extension of the proposals, the schedule of bids form is prepared in triplicate in one operation, by typewriting, and one copy filed respectively in the office of the Bureau of Highways, the Director of the Department of Public Works and the City Controller. The schedule of bids form contains the schedule letter, the character of the work and the date of letting; the location, items, estimated quantities, unit and total bid prices for each particular parcel of work; and, the name and address of the bidders. From the data shown on this schedule are determined the successful or lowest bidders.

Statement for Newspapers. Immediately after the receipt of bids a statement is prepared for the several local newspapers indicating names of the streets upon which the proposed work will be done, the number of contracts and the estimated value of each class of work upon which bids were received. If it is possible to do so, the names of the low bidders are also given.

Report of Low Bidders and Prices. After the bids have been scheduled a report of the low bidders and prices is prepared. From this report a statement is prepared and submitted to the Chief of the Bureau giving the total quantities and unit bid

prices for grading and each character of pavement and its component parts; and the total amounts of the low prices for the work included in each schedule. Another statement is also prepared and submitted to the local newspapers and certain selected technical journals indicating similar data except for the addition of the names and addresses of the low bidders and the omission of the prices on the component parts of pavements.

Disposition of Certified Checks. A record of all the certified checks accompanying the proposals is prepared in triplicate on certified check and contract award record forms and two copies are forwarded, together with the certified checks to the office of the Director of the Department of Public Works. The duplicate copy is receipted and returned to the Bureau of Highways for file, while the original copy is retained in the Director's office and receipted by the bidders to whom the checks are returned. The check of the successful bidder is retained, however, until the execution of the contract.

Award of Contract. The triplicate copy of the contract award form is forwarded to the Director's office accompanying the schedule of bids and constitutes, after being signed by the Chief of the Bureau of Highways, the formal recommendation for the award of the contracts as indicated. If the recommended awards are approved, the triplicate copy is signed by the Director and returned to the Bureau of Highways, as the formal approval of the award. All three copies of this form indicate the character of the work advertised; the schedule letter and date of receipt of bids; the name and address of the bidders; and, the amount of their certified checks, and certain other procedure data which varies according to the specific function of each of the three forms. Upon the receipt of the approved contract award recommendation there is entered on the contract record the following data: the name and address of the contractor; the date of the award of the contract; the amount of the certified check; the items and estimated quantities of the work to be performed; the unit and total prices bid and the duration of the maintenance guarantee period.

Execution of Contract. Unless the governing conditions are such that the physical construction work can not be performed within a reasonable time, the Director of the Department of Public Works is asked to request the Department of Law to prepare the contract and have it executed. This request is accompanied by four copies of the proposal form and specifications applying to that particular parcel of work. These copies of the contract are ultimately disposed of as follows; one copy is given to the contractor, and one filed in the offices of the Mayor, the Department of Law and the Bureau of Highways respectively. From the requests for the execution of a contract is determined and entered upon the contract record the following data: The contract number and the date on which it is ordered executed; the amount of the penal bond; the amount of the funds allotted to the contract; the appropriation item number; the amounts of both assessable and non-assessable liabilty and the time allowed for the completion of the work. Upon the receipt from the Department of Law of an executed contract, the date of execution is recorded on the contract record, after which the contract is signed by the Chief of the Bureau of Highways, the Director of the Department of Public Works and the Mayor. Formal notice is sent to the Bureau of Highways of the date on which the contract is approved and signed by the Mayor and this is also noted on the contract record. Copies of the proposal form and, if necessary, the specifications are then forwarded respectively to the contractor, the district assistant engineer and the district surveyor.

Rejection of Bid or Annulment of Contract. When conditions arise that necessitate or make advisable the rejection of bids or the annulment of a contract there are noted on the contract record the date and the reason for the action that is recommended. The matter is referred by the Chief of the Bureau of Highways to the Director of the Department of Public Works for his approval and appropriate action. Upon notice of the Director's approval of the recommended action, the date of the approval is entered on the contract record, and also the date of the final disposition of the matter. When bids are rejected or a contract annulled, the contract record is noted, Inactive, see revised record, and, after being initialed by the respective division engineer, is filed in the inactive file. For every record so filed a new record is originated and noted Revised record. The revised record contains all the pertinent data shown on the inactive record.

Notice to Contractor to Proceed with Work. When a contract has been signed by the Mayor and all the requested releases for a specific street have been received and

there exists no other reason for further delaying the prosecution of the work, an undated notice to the contractor to proceed with the work is prepared, and placed in the Available Notices to Proceed file from which file the notices are removed by the respective division engineer as rapidly as the contractors' working capacity will permit and are issued by the Chief of the Bureau to the contractor. The date of the issuance of the notice to proceed is entered on the contract record. Copies of the notice to proceed are furnished to the following: The contractor, accompanied by a copy of the drawings; the district assistant engineer; the district surveyor; the Bureau of Water; the permit division of the Bureau of Highways and any municipal bureau or public utility which desires to do work that cannot reasonably be done in advance of the highway construction work. The necessity for this latter notice will be ascertained by reference to the notes on the contract record requesting it. If a notice to proceed is recalled, the above indicated bureaus or public utilities are notified of the fact and the date of its recall noted on the contract record. In general a notice to proceed is never issued until all structural work is finished. When there exists an urgent necessity for the issuance of a notice to proceed with a portion of the work prior to the completion of certain structural work, a statement of understanding and agreement accompanies the notice to proceed sent to the contractor by which the contractor agrees to defer the laying of pavement at the locations where sub-surface or surface structural work is in progress. Copies of this letter are forwarded also to the municipal bureau or public utility involved and the district assistant engineer.

Division Engineers' Progress Reports. On each fourth Monday morning, the division engineers submit to the Chief Engineer a statement of the status of all the work under contract in their respective divisions. These reports contain a record of the character and limits of the work; the name of the contractor; the status of the structural conditions and of the contract; and the dates, if any, of the issuance of the notice to proceed and of the starting of the work.

Inspectors' Daily Progress Report. For each day that the physical construction work is in progress the inspector supervising the work transmits to the main office a daily progress report (see Form J). This report indicates the character and limits of the work under contract; the character, quantity and location of the work performed;

FROM TO

WORK	PERCENTAGE FINISHED TO DATE 0 10 20 30 40 50 60 70 80 90 100	QUANTITIES OF WORK PERFORMED ON THIS DATE	
SUB-GRADING			C.Y.
BASE COURSE			C.Y.
GUTTERS			S.Y.
BINDER CUSHION COURSE			S.Y.
SURFACE COURSE			S.Y.

DAYS ALLOWED	DAYS CONSUMED	CONTRACTOR	DATE

FORCE	TOTAL NUMBER	FORCE HOURS	EQUIPMENT	TOTAL NUMBER	FORCE HOURS	EQUIPMENT	TOTAL NUMBER	FORCE HOURS
FOREMEN			SINGLE TEAMS			STEAM SHOVELS		
STEAM ENGINEERS			DOUBLE TEAMS			SACRIFIERS		
PAVERS			MOTOR TRUCKS			ROAD SCRAPERS		
RAMMERS			CONCRETE MIXERS			ROAD ROLLERS		
RAKERS			CONCRETE CARTS			SPRINKLERS		
LABORERS			-TON ROLLERS					
DRIVERS			-TON ROLLERS			WEATHER		
HELPERS			HEATER WAGONS			TEMPERATURE: MAX. MIN.		

DAILY PROGRESS AND FORCE REPORT ON CONSTRUCTION WORK	TOTAL HOURS OF WORK IN PROGRESS	INSPECTOR

Form J

the name of the contractor; the number and total hours of time for each class of labor and equipment; the total hours during which the work was in progress; the inspector's signature and the date of the report. These reports are in such detail that, if it is desired to do so, they may be used to plot the progress of the work on a progress map From the first report submitted there is entered on the contract record the date of the

starting of the work. After being inspected by the respective division engineers, the progress reports for each parcel of work are filed together chronologically.

Completion of a Contract. Upon the satisfactory completion of a contract, the district assistant engineer will certify the fact to the main office, and will also indicate on a separate report whether or not this work was finished within the time allowed for its completion. If the work has not been finished within the allowed time, the number of days of delay is reported and entered on the contract record. If there is no reasonable excuse for the delay the liquidated damages provided for are charged against the contract, after being approved by the division engineer, the Chief of the Bureau of Highways and the Director of the Department of Public Works. The number of days for which the damages are exacted is recorded on the contract record. The inspector or inspectors assigned to the supervision of contract work are required to execute for the period of their assignment a certification indicating that the work was performed in strict accordance with the drawings and specifications. Based upon this report of the completion of the work, the district surveyor is authorized to prepare final estimates and bills, and the date of the completion of the work is recorded on the contract record.

Final Estimates. Upon the receipt from the district surveyor of the final estimate and bill for the work performed the following data is recorded on the contract record: The actual quantities and cost of the work performed; the assessable, non-assessable and total liability; and the length in feet of the highway affected. All estimates are subject to the joint approval of the inspector assigned to supervise the work, the district assistant engineer, the division engineer and the Chief Engineer.

General Operating Instructions. The responsibility for the operation of the contract procedure is centralized and is under the supervision of the principal assistant engineer. The records are available for general use only on application to those in charge of the details and filing system and no individual records may be removed from the files. In general, the contract records are filed alphabetically, followed by numbered streets, filed numerically. The contract records are advanced thru the several divisions of the procedure as rapidly as conditions will permit, and a frequent check of the records in each division is made to insure that their progress is not unnecessarily delayed. All entries on the contract records are made in black ink, except data pertaining to assessable liability, which is made in red ink. Rubber stamps are used for entering data wherever their use will economize time or enable the data to be more rapidly interpreted. The date and serial registeration filing number of all data recorded is also noted on the contract record.

14. General Clauses in Specifications

The different activities of a highway department require that many specifications be written. It is desirable, in order to avoid misunderstandings and promote uniformity in practice, that all the general clauses of specifications used in a given department, and, if practicable, in all departments of a given state, county, township or municipality be identical. These clauses should also be in the chronological order in which the different matters to which they relate will present themselves to prospective bidders, and all clauses relating, or interrelating, to a particular subject should be grouped. One of the great troubles with specifications is that the general clauses are scattered thruout the specifications, and very often a particular clause is repeated several times. The following Standard General Clauses for the Specifications for the Department of Public Works of Philadelphia were compiled in 1915 by a committee composed of George S. Webster, Chief of Bureau of Surveys; Carlton E. Davis, Chief of Bureau of Water; and W. H. Connell, Chief of Bureau of Highways and Street Cleaning, Chairman.

Standard General Clauses for Specifications of the Department of Public Works of Philadelphia, as adopted in 1915, are as follows:

It is understood and agreed that everything herein contained, and also the proposal or bid, are hereby made part of these specifications.

Definition of Terms. Wherever, in these specifications, the following words and expressions, or pronouns used in their stead, occur, they shall have the meanings here given: City shall mean the City of Philadelphia. Director shall mean the Director of the Department of Public Works. Engineer shall mean the Chief of the Bureau of, insert here the name of the Bureau issuing the specifications, acting directly or thru his properly authorized agents, such agents acting severally within the scope of the particular duties entrusted to them. Contractor shall mean the party of the second part to this agreement. Wherever in these specifications or upon the drawings the words directed, required, permitted, ordered, designated, prescribed, or words of like import, are used, it shall be understood that the direction, requirement, permission, order, designation, or prescription of the Engineer is intended, and similarly, the words approved, acceptable, satisfactory, or words of like import, shall mean approved by, or acceptable to or satisfactory to the Engineer, subject in each case to the final determination of the Director.

Work to be Performed. Each Bureau will insert here a general description of the work to be performed, and also a list of drawings, if any.

Qualifications of Bidders. Bidders must be responsible and capable of performing the work called for by the drawings and specifications. Bidders must carefully examine the drawings, specifications, exhibited schedules, and proposal and contract forms before submitting their proposals.

Examination of Site. Bidders must examine the location of the proposed work and make themselves acquainted with the conditions on the ground and the character of material to be encountered.

Time. Bidders will take notice that the time for the completion of the work is based upon working days, said time being fixed by the Department of Public Works and is named in the proposal form.

Proposal. All proposals must be made upon the proposal forms, which are obtained at the office of the Engineer. Proposals which contain any omissions, erasures, alterations, additions not called for, conditional bids or irregularities of any kind or proposals otherwise regular which are not accompanied by a guaranty bond or a certified check and a certificate from the Department of Law that a bidding bond has been filed or upon which the surety is not named, may be rejected as informal.

Method of Expressing Bid Prices. All bids must be written with ink in words and figures and for each item where a price is called for. In case of discrepancy the written words shall be considered as being the prices bid.

Proposal Bond. The ordinance approved May 25, 1860, requires each bidder to file in the Department of Law a bidding bond in the sum of $500, and to enclose with the proposal a certificate from the Department of Law that such a bond has been filed, but when the total amount of the bid is less than $500, no proposal bond will be required. If the bidder to whom the contract shall have been awarded shall refuse or neglect to execute the contract within 10 days after being notified so to do, the amount of the bond shall be forfeited to and retained by the City as liquidated damages for such neglect or refusal.

Naming Sureties. Every proposal must name the sureties that will be furnished on the required bonds. Contractors will not be permitted to change the sureties on the bonds submitted by them, if they are from responsible sources.

Guaranty for Execution of Contract. Each proposal must be accompanied by a guaranty bond that the bidder to whom the contract is awarded will enter into the contract. Such guaranty shall be either a bond or a certified check as stipulated in the proposal. In case a bond is called for, such bond shall be executed by a responsible surety company upon the blank form furnished for that purpose, that the bidder will, if awarded the contract, execute such contract within 10 days. In case a certified check is stipulated, such check shall be in the amount indicated in the proposal. All certified checks, except that of the successful bidder, will be returned within 3 days after the contract is awarded. When the award of the contract is deferred for a period of time longer than 10 days after the receipt of bids the certified checks will be returned, provided there is substituted a bond for an equal amount prepared in form suitable to the city solicitor. Checks of successful bidders will be returned when the contract is executed and the surety bond is filed.

Method of Submitting Proposals. Proposals should be submitted in sealed envelopes furnished with the several blank proposal forms by the Engineer. Proposals shall be

deposited in the proposal box at Room 216, City Hall, Philadelphia, Pennsylvania, until 12 o'clock noon on the date indicated in the proposal form, at which time all bids will be publically opened and read in Room 225.

Estimate of Quantities. The estimate of quantities is approximate and is stated only for the purpose of comparing bids and determining the low bidder.

Presence of Bidders. Bidders are invited to be present at the opening of bids.

Unbalanced Bids. Bids in which the prices are obviously unbalanced may be rejected.

Right to Reject Bids. The Director reserves to himself the right to reject any or all bids, as he may deem best for the interests of the City.

Time in Which to Execute Contract. The bidder to whom the award shall have been made must execute the contract within 10 days after being notified so to do by the City Solicitor.

Surety Bond. The bidder to whom the contract is awarded will be required to execute a bond for the faithful execution of the work in the sum of one-half the amount of the contract, in accordance with ordinance approved July 5, 1870.

Cancellation of Award. The Director reserves the right to cancel the award of any contract at any time before the execution of the same.

Penal Bond. In addition to the surety bond, and in accordance with an ordinance approved March 30, 1896, entitled "An Ordinance for the protection of sub-contractors, as well as persons furnishing materials and labor for the construction of buildings for the City of Philadelphia or for any other City work," also a supplement to the same approved April 8, 1909, the Contractor will be required before commencing such work, to execute penal bonds in sums as follows:

Amount of Contract	Percent of Amount of Contract
For $5 000 and less	50
Over $5 000 and less than $10 000	40
For $10 000 and less than $20 000	35
For $20 000 and less than $50 000	30
For $50 000 and less than $100 000	20
For $100 000 and less than $250 000	15
For $250 000 and upwards	10

Charges of Department of Law. The charges made by the Department of Law in connection with the preparation of bonds and contracts are fixed by Ordinance of Councils approved March 28, 1881, and are as follows:

Proposal bonds	$2 each
Other bonds, contract, penal, etc	$5 each
Contracts involving:	
$1 000 or less	$3 each
Over $1 000 and not exceeding $5 000	$5 each
Over $5 000 and not exceeding $10 000	$10 each
Over $10 000	$20 each

Laws and Ordinances. All Ordinances of the City of Philadelphia, Laws of the State of Pennsylvania and of the United States shall be observed by the Contractor. Any contract awarded under these specifications will be subject also to the provisions of the following Acts of Assembly and Ordinances of Councils: (1) Act approved June 25, 1895, and Ordinance approved Dec. 16, 1896, providing that none but citizens of the United States shall be employed in any capacity on municipal work; (2) Ordinance approved Nov. 26, 1894, and the Amendment thereto approved Dec. 28, 1895, relating to the preparation and use of stone that may enter into work done under contract with the City; (3) Ordinance approved Dec. 10, 1901, providing that competent workmen shall be employed.

Time of Commencement and Completion. The Contractor shall begin work within . . . days from the date of the notice given to that effect by the Engineer, and shall complete all work under this contract within the time specified which will be reckoned from the date of the expiration of said notice.

Patented Appliances, Products or Processes. The Contractor agrees to indemnify and save harmless the City, the Director and his assistants from all suits or actions of every nature and description brought against them, or either of them, for or on account of the use of patented appliances, products or processes.

Material Samples. No materials shall be used in the work unless conforming to the requirements of these specifications, and before any contract is awarded bidders will be required upon request of the Engineer to furnish a complete statement of the origin, composition and manufacture of all materials to be used on the work, together with samples of the same, which samples may be subjected to the tests herein provided to determine their quality and fitness for the work and must all meet such tests to the satisfaction of the Engineer. The Contractor shall furnish any additional samples when required and permit any designated representative of the Engineer to inspect any and all materials being used or desired to be used at any time before, during, or after its preparation, or while being used during the progress of the work, or after the work is completed and all such material not conforming to the requirements of the specifications, whether in place or not, shall be rejected and shall be immediately removed from the work.

Fixed Prices for Contingent Work. The attention of bidders is called to the fixed prices for contingent work given in the proposal. It is understood that all definitely anticipated incidental work will be included in the estimate of quantities, and that bid prices for such incidental work will be asked for. The Contractor will, however, be required to do at the specified fixed prices any other incidental work not included in the estimate of quantities, which may become necessary to the proper execution of the contract. Where a price is asked for on the proposal form for any such incidental work, it is also understood that the unit price bid will govern for all work of this class, even altho a fixed unit price for such work be specified, and even if the estimate of quantities be exceeded in the performance of any contract.

Additional and Contingent Work. The Contractor shall do such additional work, other than that designated in the estimate of quantities, as may be necessary in the opinion of the Engineer, to fully complete the work as planned and contemplated, and will receive in full payment for such additional work the prices shown in the proposal or in the schedule of fixed prices for contingent work, and in the same manner as if such work had been included in the original estimate of quantities. Whenever such additional work comprises or consists of work coming under the several classifications for which fixed prices are named in the schedule of fixed prices for contingent work and for which no price is included in the proposal, the work shall be done for the unit prices named therein, and it shall be agreed by any Contractor executing any contract based upon these specifications, that the unit prices named therein will be accepted as full payment for any such contingent work, and such contingent work shall be done in accordance with the latest standard specifications of the Department of Public Works. Any additional work not included in the proposal or in the schedule of fixed prices for contingent work will be done at a price to be agreed upon in writing by the Contractor and the Engineer and approved by the Director.

Special Requirements. Should any construction or condition be anticipated on any proposed work, which is not covered by these specifications, the requirements thereof will be stated on the proposal form and any such special requirements shall be considered a part of these specifications, as tho they were fully contained herein. Should any such special requirement conflict with any of the provisions of these specifications, the special requirement stated on the proposal form shall govern.

Specifications and Drawings Modified by Written Agreement. The specifications and the drawings herein referred to may be modified and changed from time to time as may be agreed in writing between the Director and the Contractor in a manner not materially affecting the substance thereof, if such changes are necessary to carry out and complete more fully and perfectly the work agreed to be done and performed. If such changes and modifications increase the expense of the work, the increased expense will be paid by the City. If such modifications and changes diminish the expense of the work, the amount of said diminution may be retained or withheld by the City. No consequential loss or profit on work not executed shall be paid to the Contractor. Should the Director and the Contractor not be able to agree upon modifications and changes deemed essential by the Director, the Director may at his option cause work involved therein to be executed under a separate contract. In such a case, the work under the original contract shall be suspended, if necessary, until the changes are completed. The Contractor shall give every facility for making these changes and will not be allowed compensation for the delay except by an extension of the time for the completion of the contract.

Equipment and Material. The character, quality and quantity of equipment shall

be such as is necessary for the proper execution of the work within the specified time limit. The Contractor shall furnish all material required, which shall be in full accordance with the specifications and the general and detailed drawings.

Competent Workmen. The Contractor shall employ only competent and efficient laborers and first-class mechanics or artisans for every kind of work, and whenever, in the opinion of the Engineer, any man is unfit to perform his task, or does his work contrary to directions, or conducts himself improperly, the Contractor must discharge him immediately and not employ him again on the work.

Prosecution of Work. The work under this contract shall be prosecuted at and from as many different points, at such times, and in such part or parts of the work, and with such force of workmen and equipment as may be ordered by the Engineer.

Drawings and Specifications to be Kept on Work. The approved drawings and a copy of the specifications shall be left constantly on the work by the Contractor.

Supervision. The work shall be at all times subject to the supervision of the Engineer and of his authorized assistants, who shall have free access and every facility at all times afforded them for inspection.

Engineer to Give Orders, Explain and Decide. To prevent all disputes and litigation, the Engineer shall in all cases determine the amount or quantity of the several kinds of the work which are to be paid for under this contract, and he shall determine all questions in relation to the work and the construction thereof, and he shall in all cases decide every question which may arise relative to the performance of the work covered by this contract on the part of the Contractor. Any doubt as to the meaning of these specifications or any obscurity as to the wording of them will be explained by the Engineer, and all directions and explanations requisite or necessary to complete, explain or make definite any of the provisions of these specifications and give them due effect, will be given by the Engineer.

Inspection. Duly authorized inspectors will be assigned to the work or each part thereof who shall perform their duties under the direction of the Engineer. The Contractor shall execute his work in the presence of the Inspector and during the working hours of the day, unless specially directed otherwise, and shall afford every facility for inspecting the materials and work at all times. The presence of the Inspector shall in nowise lessen the responsibility of the Contractor.

Examination of Work. The Engineer shall be furnished with every reasonable facility for ascertaining whether the work is in accordance with the requirements and intention of this contract, even to the extent of uncovering or taking down portions of finished work. Should the work thus exposed or examined prove satisfactory, the uncovering or taking down and the replacing of the covering, or the making good of the parts removed, shall be paid for at the contract prices for the class of work done; but should the work exposed or examined prove unsatisfactory, the uncovering, taking down, replacing and making good shall be at the expense of the Contractor. All defective work which has been condemned shall be immediately removed by the Contractor and at his expense.

Defective Work. Any materials or workmanship of inferior quality, or not in accordance with the approved plans and these specifications, brought to or incorporated in the work, shall be immediately removed by the Contractor from the vicinity or built anew; and if the directions of the Director are not complied with after written notice, the said Director shall be at liberty to remove the same at the expense of the Contractor and deduct the cost thereof from any money which may be due. Materials and workmanship may be reinspected at any time. The Contractor shall furnish all necessary facilities, should it be deemed advisable by the Director to make an examination of any work already completed. If the work be found defective in any respect, the Contractor shall defray all expenses of such examinations and of proper reconstruction. If the work be found satisfactory, the expenses will be allowed for.

Suspension of Work in Freezing Weather. Work liable to be affected by frost shall be suspended during freezing weather, unless permission for continuance be given in writing, and then only for such times and under such conditions as may be specified. Upon suspension, the work shall be covered and protected as directed.

Personal Attention of Contractor. The Contractor shall be responsible for the entire work until it is completed and accepted by final payment. He shall give his personal supervision to the faithful prosecution of the work; he shall not sub-let or assign the contract but shall keep it under his own control. In case of his absence, the Contractor

shall have a competent representative or foreman on the work, who shall receive orders and directions from the Engineer, or the Engineer's representative, and who shall have full authority from the Contractor to execute these orders without delay and to supply materials, tools and labor.

Sub-Contractors. No portion of the work shall be sub-let to any sub-contractor without first giving the Engineer due notice in writing of such intention. No Subcontractor shall be employed who is unsatisfactory to the Engineer.

Disputes Between Contractors. In case of disputes arising between Contractors on adjacent work, the decision of the Engineer shall be final and binding upon the parties affected.

Permits and Licenses. The Contractor must pay for all permits and licenses; all fees and other charges from City, County or State officers, except where otherwise particularly noted in these specifications. The Contractor will be required to take out a permit for the removal and underpinning of buildings that are to be removed or underpinned under this contract, from the Bureau of Building Inspection, and to observe all the rules and regulations of the Department of Health.

Use of Water. Permits for the use of water upon construction work may be obtained from the Chief of the Bureau of Water upon application to the Engineer and subject to the following requirements of the Bureau of Water: The Contractor shall be responsible for leaving the hydrants in perfect condition; for all damage caused in the vicinity by water leaking from hydrants, and for any damage to the water mains within a reasonable distance of the hydrants used, which may be caused by improper connection of the hydrants. He shall report to the Bureau of Water all hydrants from which water is to be taken by authority of the permit, together with the condition of the hydrant before using, and shall be responsible for leaving the hydrant in a satisfactory condition. The permit will not be effective until it is approved by the Engineer. Upon the completion of the work the Contractor will be required to obtain a certificate from the Bureau of Water that the terms of this agreement have been complied with. Should the Contractor at any time waste the water, the permit will be revoked by the Chief of the Bureau of Water. On the completion of the work for which the permit is issued, the Contractor must return to the Bureau of Water all permit cards issued for the use of fire hydrants, under a penalty of $15 for each permit. This sum to be deducted from any money due to Contractor. No charge will be made for the use of water.

Accessibility of Fire Hydrants. The fire hydrants adjacent to the work shall be kept at all times readily accessible to fire apparatus and no material or other obstruction shall be placed within 5 ft of any such hydrant.

Blasting. Blasting will not be allowed unless the Contractor first obtains a permit from the Department of Public Safety, thru the Department of Public Works, and then only on condition that all blasting powder, dynamite, etc, shall be kept in a secure and approved manner, shall be at all times under the especial care of a watchman, and that each blast shall be covered with heavy timber or mats before firing, when so directed. The City reserves the right to revoke such permit at any time. All blasting shall be done in the most careful manner, so as not to endanger life or property; the blasts shall be fired only at such times as may be permitted, and whenever directed the number and size of charges shall be reduced; no claim for loss or delay will be allowed on this account. The explosive to be used shall be subject to the approval of the Engineer. All laws and ordinances relative to the storage and use of explosives must be observed.

Use of Coal Under Boilers. The Contractor shall in all cases where steam power is employed use anthracite coal under the boilers for generating steam, and in the built up sections of the City, when required by the Engineer, shall provide electric power for operating all power-driven machinery.

Sanitary Conveniences. Necessary sanitary conveniences for the use of laborers on the work, properly secluded, shall be constructed, if required, and maintained by the Contractor, and their exclusive use strictly enforced.

Danger Signals. The Contractor shall erect and maintain all necessary barricades, red lanterns and danger signals. The lights shall be kept burning from twilight until sunrise, and a watchman shall be provided for the safety of the public. The Contractor shall observe such rules relative to signals and safeguards as the police regulations, laws and ordinances require.

Responsibility for Damages. The Contractor shall assume all responsibility for risks and casualties of every description arising out of the nature of the work, the action of the elements or unforeseen or unusual difficulties. The Contractor shall assume all blame for loss by reason of neglect or violation of state, or City ordinances or laws or regulations, loss by fire due to the work on this contract, or from any other cause and all work necessary to conform to the laws and ordinances referred to as included in these specifications.

Suits and Claims. The Contractor agrees to indemnify, defend and save harmless the City, the Director and his assistants from all suits and claims for damages, loss or injury to persons or property received or sustained, from the Contractors, his agents, or servants, in the performance of the work under this agreement. The Contractor further agrees that all or so much of the moneys due him under this agreement as may be considered necessary by the Director may be retained until all such suits or claims have been settled and satisfactory evidence to that effect furnished.

Cleaning up Site of Work. Before the work will be considered as having been completed, the site of work, streets, roads, sidewalks, buildings, and all places affected by the work, are to be thoroly cleared and left clean, free and in good order and fit for travel and other proper use.

Damages for not Completing Within Time Limit. For each working day that any work shall remain uncompleted after the time specified for the completion of the work provided for in these specifications, and the accompanying contract, the sum per day, given in the following schedule, unless otherwise specified in the proposal form, may, at the option of the Director, be deducted from moneys due the Contractor, not as a penalty, but as liquidated damages. If, however, the Contractor gives the Director a satisfactory reason accounting for the delay, the Director may, in his discretion, extend the time for the completion of the work.

Amount of Contract	Amount of Liquidated Damages per Day
$5 000 and less	$5
Over $5 000 and less than $10 000	$10
$10 000 and less than $20 000	$15
$20 000 and less than $50 000	$20
$50 000 and less than $100 000	$25
$100 000 and over	Special Damages

Cancellation of Contract. The Contractor shall not be required to proceed with the work of any contract, if for any reason, for which he is not responsible, the work cannot be commenced within 6 months from the date of execution of the contract, and in such case, at the request of the Contractor, the contract may be declared null and void.

Violation of Contract. Should the work not be completed at the specified time, or should the Contractor neglect or abandon the work, or should the Director be convinced that the work is unreasonably delayed, or that the conditions of the contract are being wilfully violated or executed carelessly or in bad faith, the said Director may notify the Contractor, in writing, and if his notification be without effect within 24 hr after the delivery thereof, then, and in that case, the Contractor shall discontinue all work under the contract, and the Director shall have full authority and power to immediately purchase and hire materials, tools, labor and machinery for the completion of the contract at the expense of the Contractor, or his sureties, or both, and any moneys due the Contractor may be used for this purpose; or the said Director may declare the contract null and void, and the security, bond and retained percentage, and the materials built into the work, and the materials delivered, and the Contractor's plant, shall then become the property of the City of Philadelphia.

Scope of Payments. The Contractor shall receive and accept the assessment bills and warrants at the prices and rates respectively named therefor in the contract as full compensation for furnishing all materials, labor, tools and equipment and for doing all the work contemplated and embraced in these specifications. Note: Here should be added such detailed information as may be necessary to specifically provide for the requirements of each of the several bureaus.

Current Estimates. At intervals of about 4 weeks during the progress of the work, the Engineer will make an estimate of the value of the work done and materials incorporated in the work, and 90% of such estimated value, when approved by the

Director, will be paid to the Contractor in warrants drawn on the City Treasurer, which the Contractor agrees to accept as cash. The current monthly estimates and payments shall not bind the City to the acceptance of any materials furnished or work done. The Contractor shall not be entitled to demand or receive payment for any work as extra work unless ordered, in writing, by the Engineer to do the same as such, and at a price approved by the Director previous to its commencement.

Final Payment. After the work embraced within the contract has been completed in accordance with these specifications, the balance due the Contractor, after all legal and equitable deductions, shall be paid him, upon the acceptance and approval of the Director.

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